Hydrogeology of the Hinds Rangitata Plain, and the Impacts of the Mayfield-Hinds Irrigation Scheme

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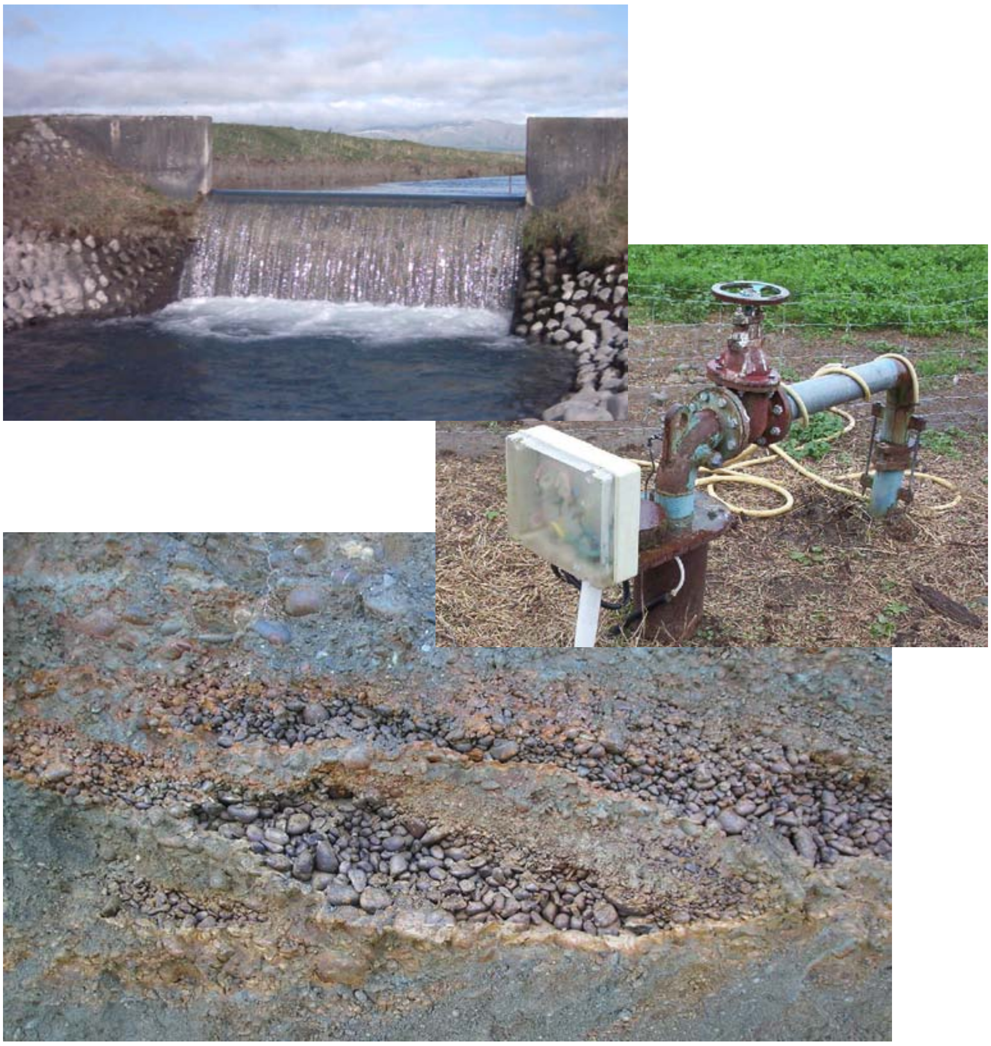

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Abstract

The main aim of this research was to gain a better understanding of the surface and groundwater systems in order to sustainably manage the resource for both current and future generations.

Three aquifers are present within the Hinds Rangitata Plain. Aquifer one extends from near surface to approximately 40 – 50 m, aquifer two occurs from approximately 40 – 90 m, and aquifer three occurs from approximately 90 – 150 m. Aquifer one is shown to occur as a series of permeable, iron stained, poorly connected and laterally discontinuous lenses, within and often separated by less permeable sandy or tight claybound gravels. Lenses range from a few centimeters to 20 m wide and from a few centimeters to 1 m thick. These permeable layers are known to be the dominant sources of groundwater from aquifer one.

In all three aquifers depth to groundwater and water seasonal water level fluctuations increase with increasing distance inland from the coast. Aquifer one gains and loses groundwater along different sections of the Hinds and Rangitata Rivers.

The Hinds Rangitata Plain can be broken into seven distinct zones based on differences in the dominant source (s) of groundwater recharge within each zone. The boundaries for each zone were determined by comparing the short-term seasonal water level fluctuations observed over the course of this study and the long-term water level records, with rainfall, river flows and Mayfield-Hinds Scheme recharge. The majority of the zones also have distinctly different groundwater chemistry and oxygen-18 ($d^{18}O$) values.

Flows in drains and the Hinds River were highly influenced by groundwater levels. Drains and springs within the Mayfield-Hinds Irrigation Scheme were highly influenced by irrigation recharge where as those closer to the coast were more influenced by rainfall.

A regional water balance of the Hinds Rangitata Plain was carried out for a one period, between September 2005 and August 2006. During this period, total recharge was 375 $m^3 \times 10^6$, total discharge was 227 $m^3 \times 10^6$, and the outflow was 148 $m^3 \times 10^6$. Data collected during the course of this study showed that rainfall recharge was dominant, accounting for 67 % of the total recharge. The Mayfield-Hinds Irrigation Scheme accounted for 30 % of the total recharge, with a relatively small contribution each from the Rangitata Diversion Race and Hinds River. In terms of discharge, the combined discharge from the drains and Rangitata River terrace springs, accounted for 62 % of the total discharge, with the remaining discharge from coming from groundwater abstraction. There are no overall losses to groundwater from either the Rangitata River or from stockwater race

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Chapter 1

Introduction

1.1 Project Background

The progressive shift to more extensive farming practices and advances in irrigation methods has increased the demand for water within the Hinds Rangitata Plain. The main aim of this research is to gain a better understanding of the surface and groundwater systems in order to sustainably manage the resource for both current and future generations.

Prior to this study, no water balance had been carried for the Hinds Rangitata Plain. In addition, little or no research had been carried out into the water level fluctuations in aquifers two, three and aquifer one near the coast, the flow regime of the Hinds Drainage Network, the sources of flow in the Hinds River, and the spatial variability of the groundwater chemistry. Previously, the most detailed research focused on the nature and occurrence of springs, aquifer one, and the affects of the Mayfield-Hinds Irrigation Scheme on first aquifer water levels.

1.2 Objectives

To gain a better understanding of the surface and groundwater resources of the Hinds Rangitata Plain, the primary objectives of this study were to:

- Delineate all aquifers present in the study area and characterize their properties.
- Determine the long-term and short-term affects of rainfall, Mayfield-Hinds Irrigation Scheme and river recharge, on groundwater levels, both spatially and with depth in all aquifers.
- Understand the affects of groundwater levels and rainfall on spring and drain flows.
- Understand the flow regime and sources of flow within the Hinds River.
- Provide a water balance showing the changes in groundwater recharge and discharge over the course of this course of this study.

- Identify the sources of recharge and groundwater flow paths based on water chemistry and oxygen-18 ($d^{18}O$).

1.3 Study Area

The study area is approximately 580 km^2 and extends inland from the coast to approximately Mayfield Township, bounded by the Hinds River in the north and the Rangitata River in the south. A copy of the study area is provided in Figure 1.1 in the text, and Figure 1.1 in the back pocket. The entire area between the Hinds and Rangitata Rivers, and from the coast to the foothills, is referred to as the Hinds Rangitata Plain. This section of the plain is located within Canterbury, on the east coast of the South Island, New Zealand. Field boundaries were loosely established to cover the area affected by the Mayfield-Hinds Irrigation Scheme and as a consequence the western inland boundary does not extend all the way to the foothills.

The field area occurs within the Mayfield-Hinds and Valetta groundwater allocation zones (Figure 1.2). These zones were developed to protect aquifers from over-abstraction and maintain the reliability of supply to existing users. The allocation limit for each zone was calculated from the best available information at the time. Based on this information the Valetta zone was over 100 % allocated and the Mayfield-Hinds zone was between 80 and 100 % allocated as of October 2006.

1.4 Physical Setting

1.4.1 General setting

The Canterbury Plains are mainly comprised of Quaternary age gravels deposited by rivers during glacial periods. Water within these gravels, also known as groundwater, flows in a general direction from the foothills to the sea, and may intercept the land surface as springs or creeks. The foothills are comprised of dominantly Mesozoic greywacke of the Torlesse Supergroup with Tertiary aged sediments and volcanics outcropping between the foothills and the study area. The elevation in the area ranges from about 400 m in the northwest down to sea level in the southeast. The average gradient is least at the coast and increases inland of State-Highway 1.

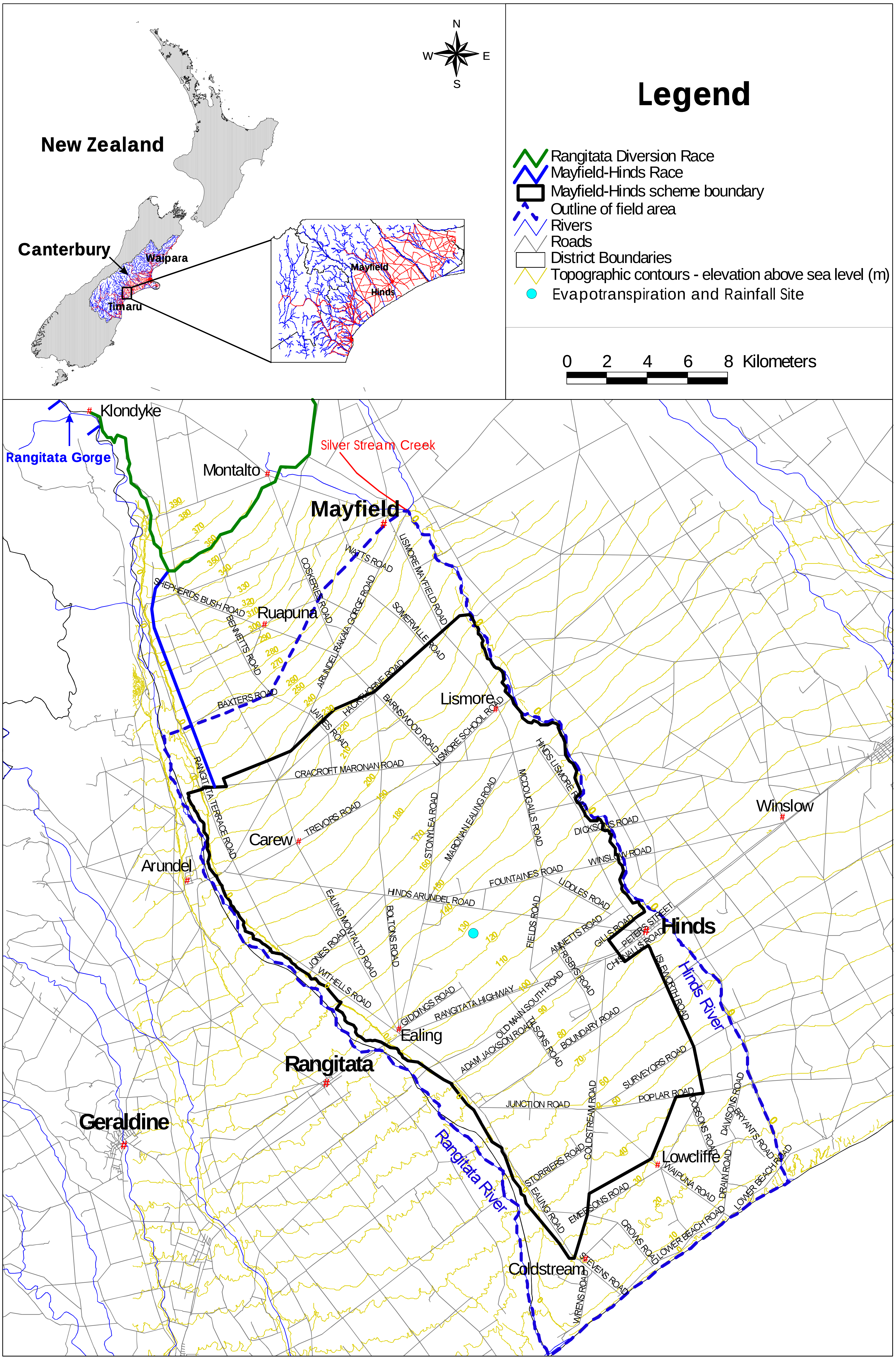

Figure 1.1 - Map showing the study area, Mayfield-Hinds Irrigation scheme and other features of interest.

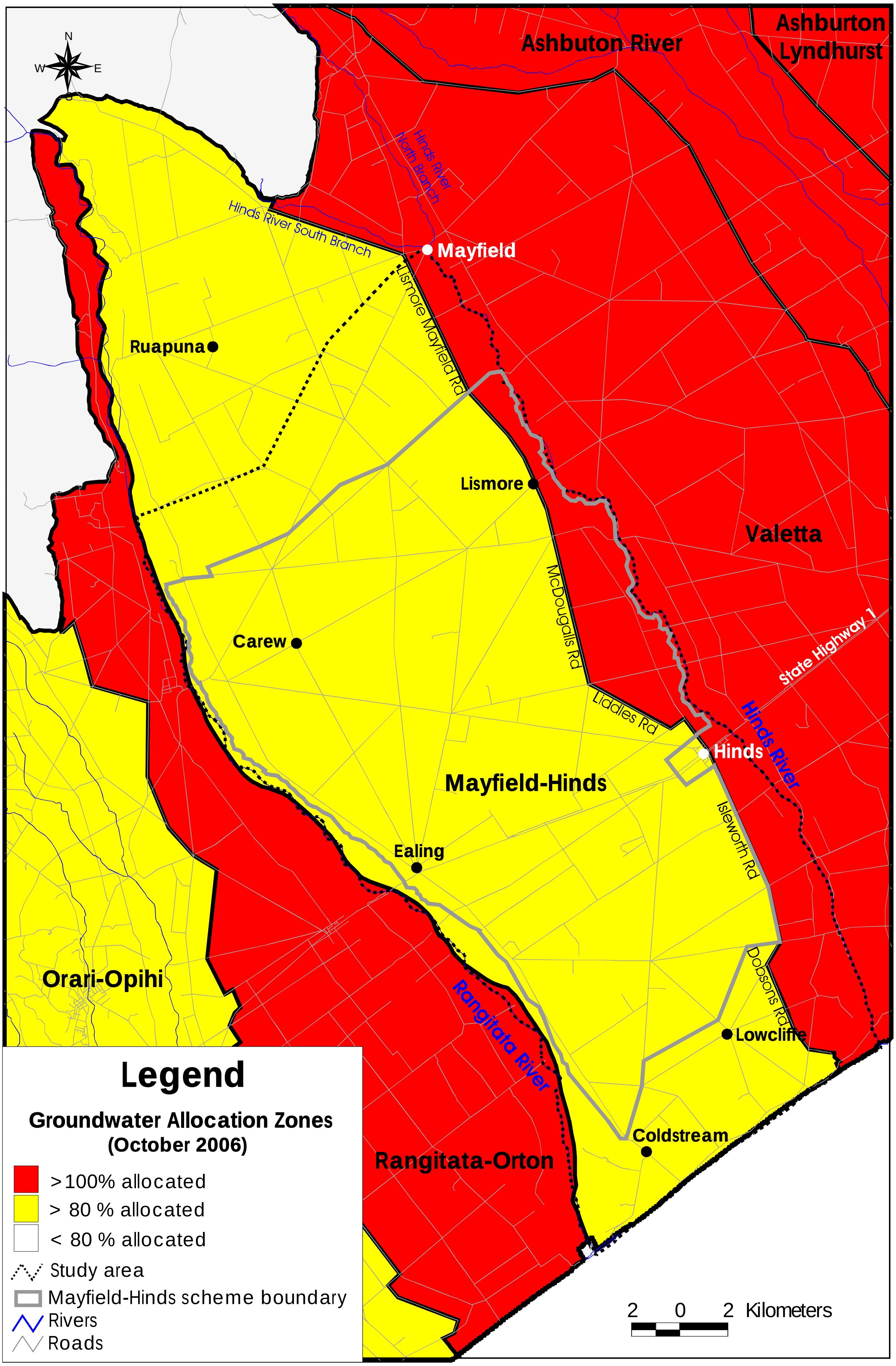

Figure 1.2 - Groundwater Allocation Zones as of October 2006.

The two major rivers in the study area are the Hinds and Rangitata. The Rangitata is formed by the confluence of three tributaries (Havelock, Clyde and Lawarence Rivers) which flow from glaciers near the main divide (Barrell et al, 1996). Below these tributaries the river flows in a braided form through a gravel intermontane basin before entering a terrace lined gorge, approximately 4 km in length (Figure 1.1). Downstream of the gorge the river flows within a terraced alluvial fan before flowing into the Pacific Ocean via a narrow lagoon at the river mouth. The mean flow of the Rangitata River is 95 m^3/s, with a maximum and minimum recorded flow at Klondyke, of 3,000 m^3/s and 30 m^3/s respectively (Mosley, 2001). The lowest mean flows occur in winter and the highest occur in early summer. Higher summer flows are caused by a combination of snow melt and higher summer rainfall (Mosley, 2001). The Hinds River is a smaller braided river, fed by a north and south branch which converge at approximately Mayfield-Bridge (Figure 1.1). Both branches are ephemeral. In addition, a small spring fed creek known as Silver Stream Creek flows into the Hinds River 200 m upstream of Mayfield Bridge (Figure 1.1). Downstream between Mayfield Bridge and Boundary Rd the river often goes dry during summer (Figure 1.1). Further downstream at Surveyors Rd, the river maintains a consistent flow from springs within the bed of the river and inflow from drains.

1.4.2 Climate

Rainfall

Most rainfall within the Hinds Rangitata Plain catchment is associated with cold southerly air masses (Sturman, 1986). However, some rainfall occasionally reaches the plains from northwest winds which are responsible for most of the precipitation in the Southern Alps. Figure 1.3 shows that mean annual rainfall increases from approximately 600 mm at the coast to 1,000 mm inland near Ruapuna with a distinct increase towards the direction of Mount Peel.

Historic rainfall data (> 40 years record) was collected from six different landowners within the study area. These sites are listed as L1 – L6 in Figure 1.3, and a table showing the mean monthly totals from each site is provided in Appendices 1.1A – 1.1F. The mean annual rainfall totals from each site show a close correlation to the rainfall contours, with an increase in rainfall inland from the coast (Figure 1.3). The mean monthly rainfall totals from each site (presented Figures 1.4 – 1.5), show that rainfall nearer the coast is more evenly distributed throughout the year. For example, at site L1, only 15 mm more rainfall occurs over summer (October to March)

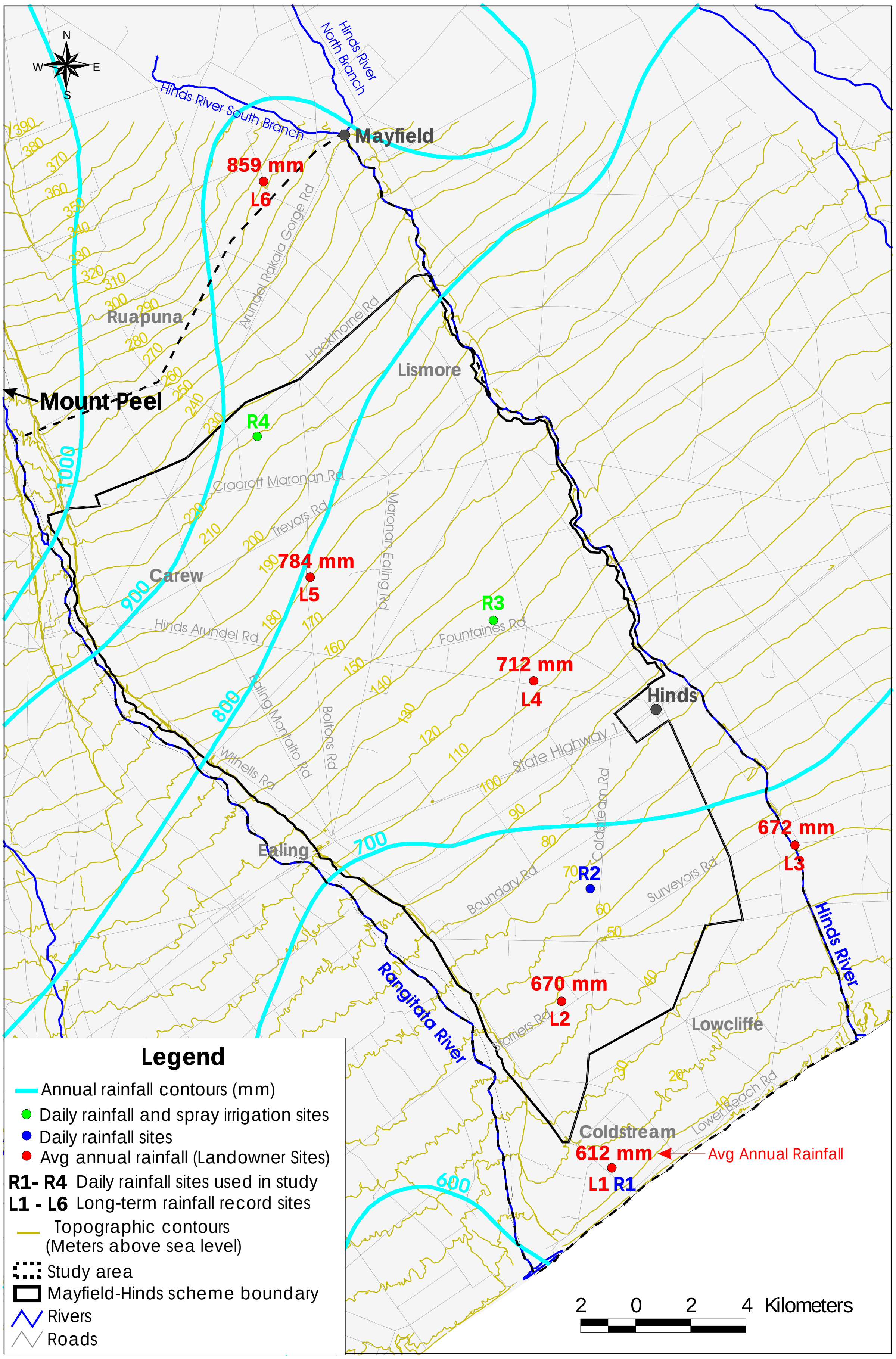

Figure 1.3 - Mean annual rainfall, historic rainfall sites and rainfall recorder sites used during this study.

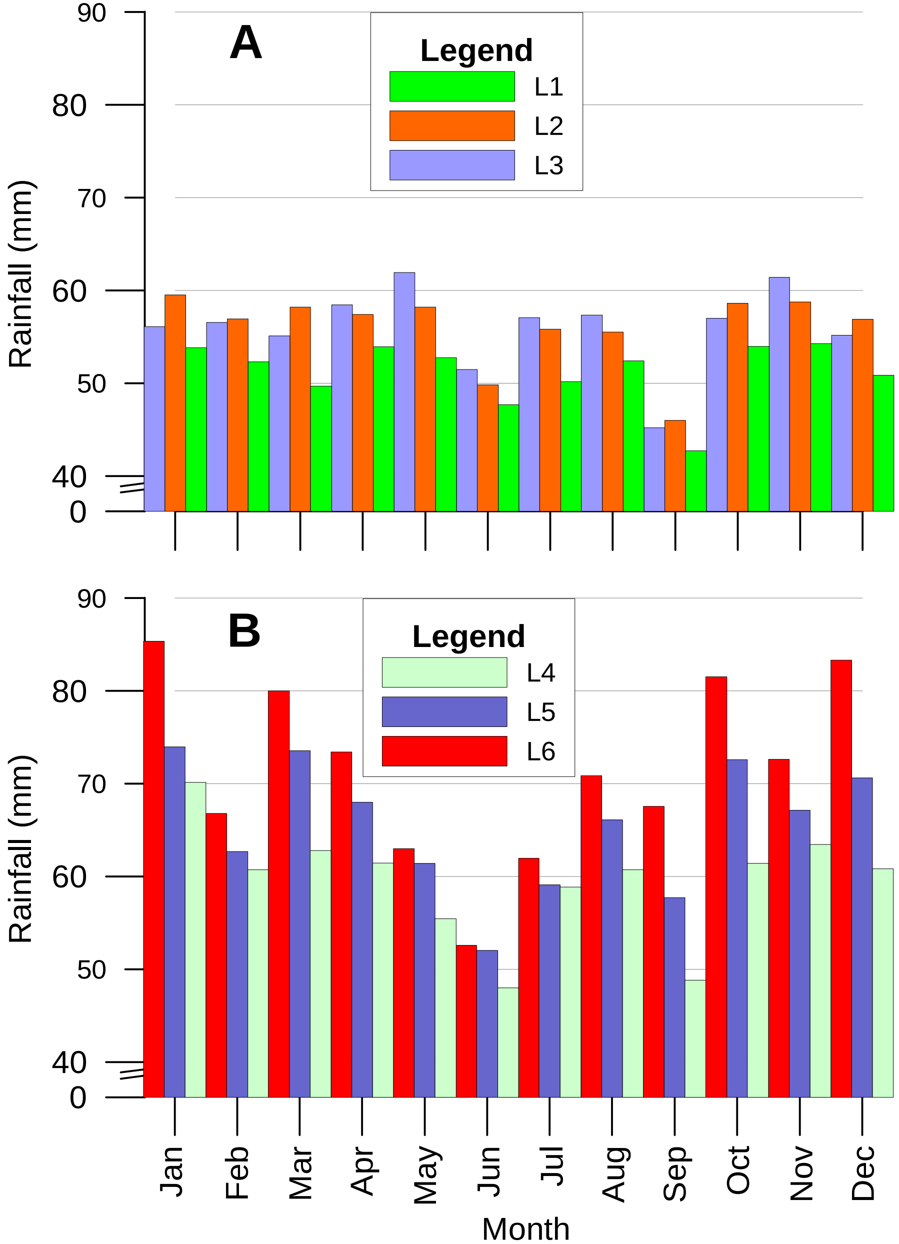

Figure 1.4 - Mean monthly rainfall for sites L1 - L6 within the field area.

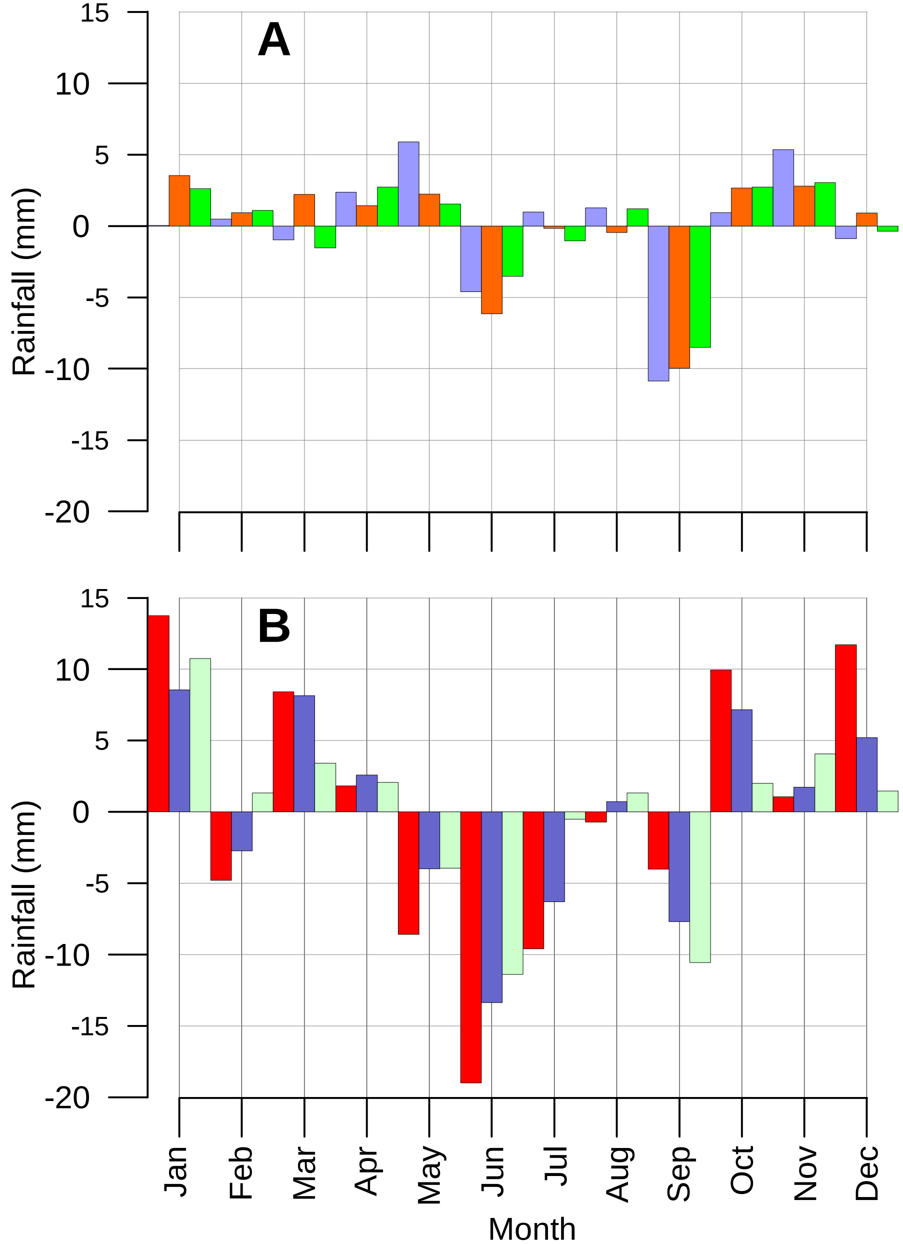

Figure 1.5 - Deviation from the mean monthly rainfall for sites L1 - L6 within the field area.

than in winter (April to September) (Table 1.1). Yet inland from the coast at site L6 near Mayfield Township, 80 mm more rainfall occurs over summer than in winter (Table 1.1). In general, the lowest rainfall occurs in June and the highest rainfall occurs between November and February.

Table 1.1 – Comparison of winter verses summer rainfall.

Date	Rainfall Site (rainfall mm)					
	L1	**L2**	**L3**	**L4**	**L5**	**L6**
Oct - Mar	315	349	341	379	421	470
Apr - Sep	300	323	331	333	364	389
Difference	15	26	10	46	56	80

Daily rainfall from sites R1 - R4 was used to compare rainfall with groundwater levels and surface water flows. The location of theses sites is shown in Figure 1.3.

Evapotranspiration

Potential evapotranspiration (PET) and rainfall data was taken from a site half way between the coast and Mayfield Township (Figure 1.1). The data is an estimate of the average monthly rainfall and PET (over a 34 year period) within a one kilometer grid. This grid was based on interpolated climate station data (Scott, 2004). Figure 1.6 shows that PET exceeds rainfall between September and March. High PET rates limit the amount of groundwater recharge from rainfall or irrigation.

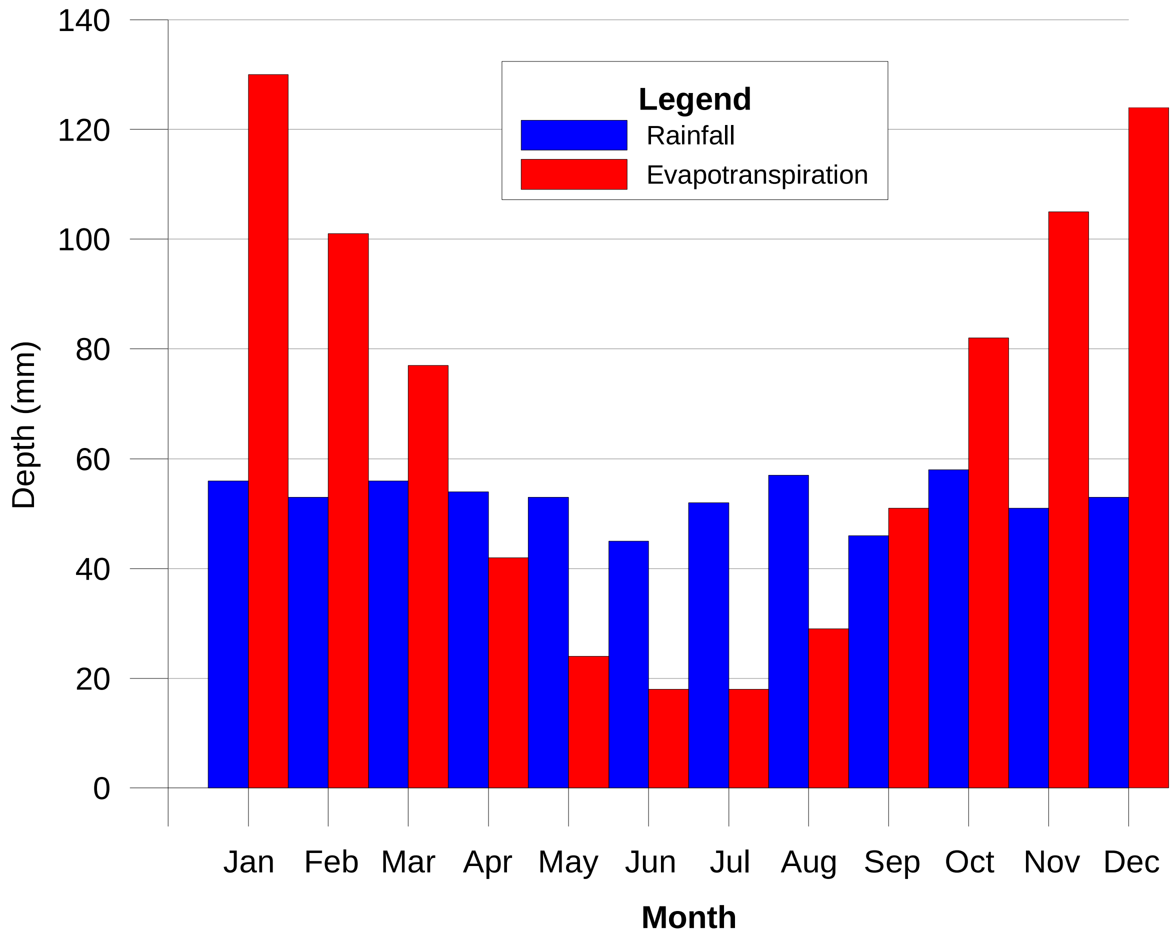

Figure 1.6 – Mean monthly rainfall and evapotranspiration near the middle of the Hinds Rangitata Plain.

1.4.3 Soils

Soils within the Hinds Rangitata Plain have developed over permeable gravel fans. A map showing the soil groups and average profile available water is shown in Appendix 1.2 and Figure 1.7 respectively. Soils within the Mayfield-Hinds Irrigation Scheme are almost exclusively Lismore (silt and stoney silt loams), and have an average profile available water (PAW avg) between 50 and 60 mm. The PAW is defined as the amount of water held within the soil that plants are expected to use. Closer to the foothills, soils are mostly Ruapuna stoney silt loam (bouldery phase), with a PAW of 60 mm.

Adjacent to the Hinds River and within the area of the former Hinds Swamp (shown in Figure 6.1), soils have a significantly greater water holding capacity. Within the former Hinds Swamp, some soils are peaty and high in organic material as a consequence of the high water table. The subsoils in this area are generally bleached or stained with iron oxide and hard pans of limonite

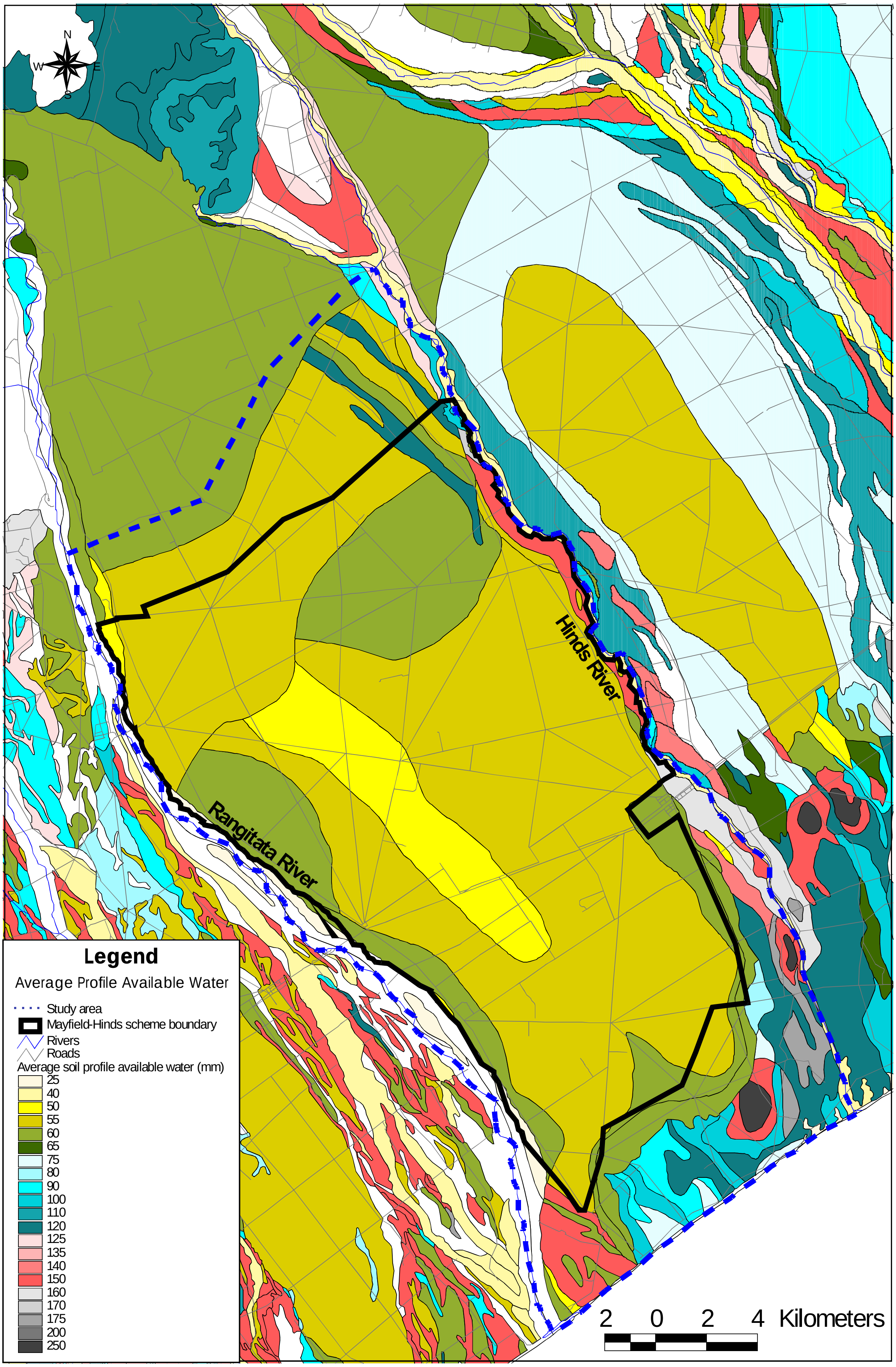

Figure 1.7 - Average soil profile available water (PAW).

commonly occur between 25 and 43 cm below ground level (Mitchell, 1980). PAW ranges between 75 - 250 mm, with an average PAW of approximately 120 mm. In addition to a lower fan gradient and consistently high water table, these heavier soils can accentuate drainage problems after heavy rainfall events. For a more detailed soil description, refer to Cox (1978).

1.4.4 Landuse

Landuse throughout the Hinds Rangitata Plain is a mixture of dairy and dairy support (milking cows and winter feed), livestock (sheep, beef, deer, pig, bull farming) mixed farming (sheep, deer, winter feed and cash crop) and crop (wheat, blackcurrants etc.) (Figure1.8). The type of landuse is largely controlled by the soils, rainfall, sunshine hours, wind and accessibility to water for irrigation and stock. For example, arable farming requires soils with moderate water holding capacities, a significant reason why the areas of crop are located on the heavier soils near the Hinds River and within the former Hinds Swamp. Since 1966 the landuse has changed from dominantly mixed farming with a significant amount of sheep and pasture to dominantly dairy, with significant pastoral land by 2006. Arable landuse has remained relatively consistent. The increase in dairy (and subsequent decline in sheep and mixed farming) has been largely facilitated by the availability of water for irrigation and improvements in irrigation methods, in addition to other developments such as fertilizers and different grass seed.

1.5 Groundwater Use and Developments over Time

The earliest recorded well was drilled in 1932. From 1930 to 1990 approximately 56 generally shallower wells (< 40 m deep) were drilled into the first aquifer with an even spread over the entire study area (Figure 1.9). Since 1990, significantly more wells have been drilled (Figure 1.9), with many more wells abstracting deeper groundwater to depths of up to 170 m. Prior to 1992, only four deep wells (between 61 and 74 m deep) had been drilled. The recent increase in drilled wells can be largely attributed to the expansion from dryland farming to more extensive farming practices, requiring a reliable supply of groundwater for irrigation.

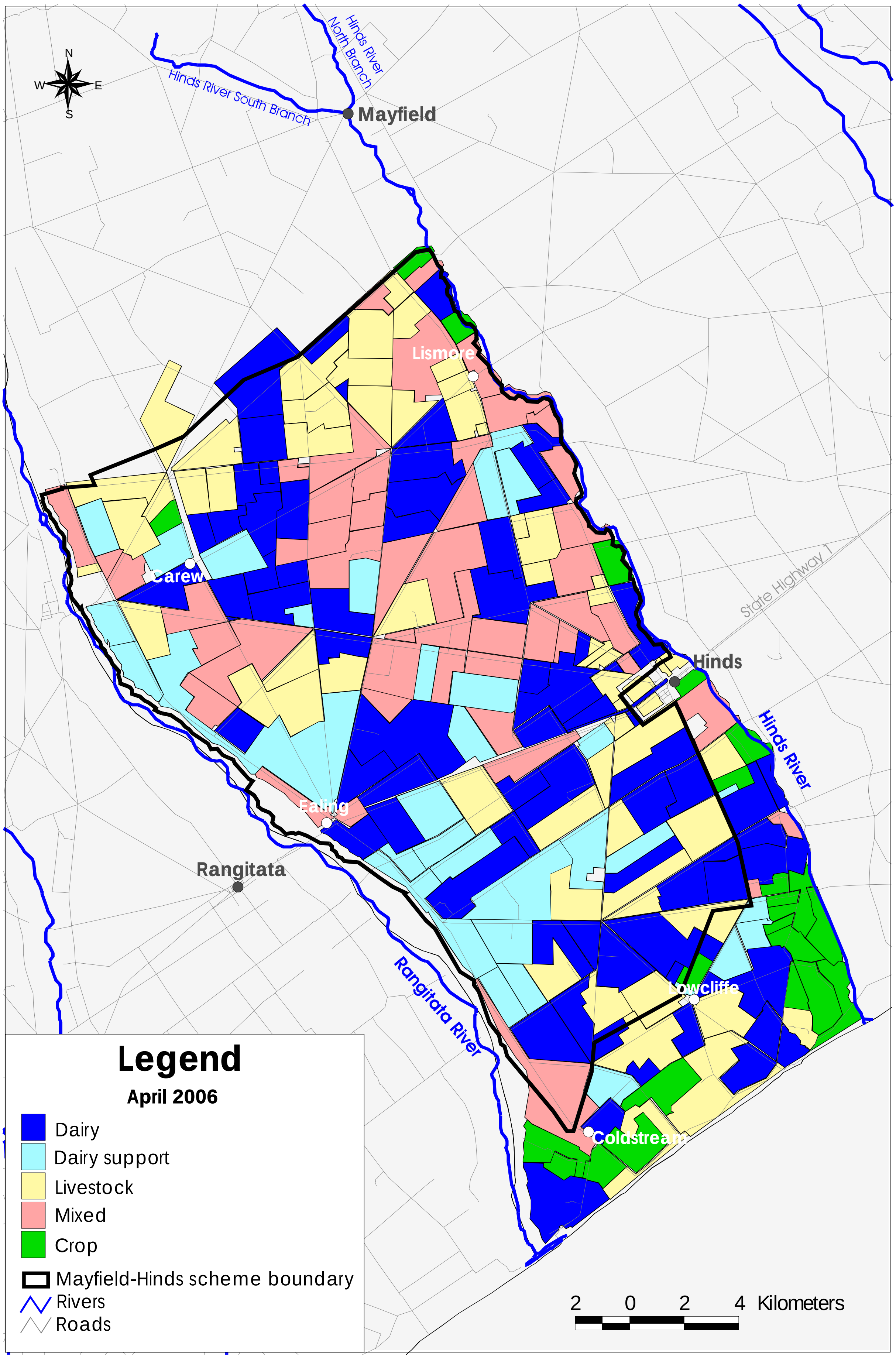

Figure 1.8 - Landuses within the Hinds Rangitata Plain area as of April 2006 (adapted from Dodson, 2006)

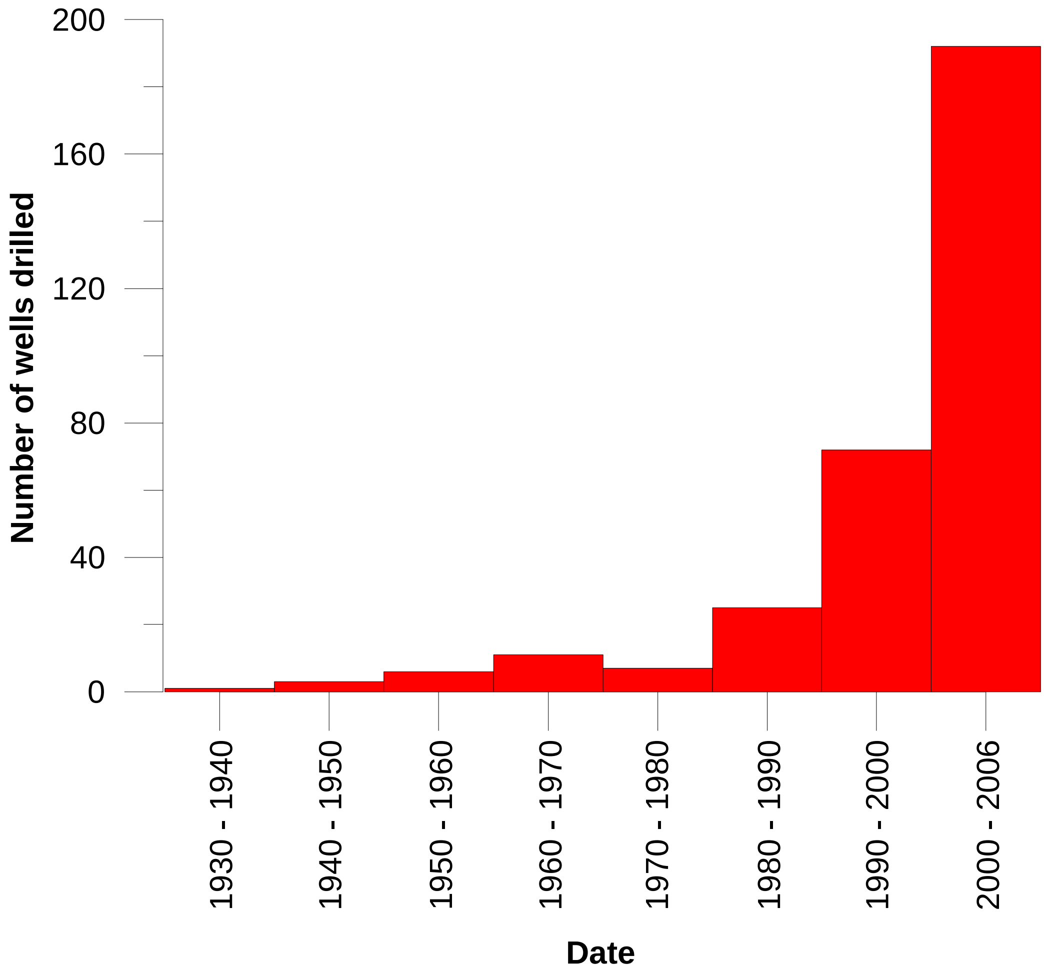

Figure 1.9 – Number of wells drilled over time within the Hinds Rangitata Plain.

As of May 2006 there were approximately 600 wells within the entire Hinds Rangitata Plain, of which 300 were used for irrigation and 160 for domestic of stockwater purposes. Shallow wells (< 30 m deep) accounted for 66 % of all wells, with 23 % between 30 and 100 m and 11 % deeper than 100 m. Figure 1.10 shows the distribution of wells both spatially and with depth. Coastward of the State Highway, the majority of wells occur in aquifer one (< 20 m deep) with a smaller but still significant number of second aquifer wells (between 40 and 90 m deep). Inland of the State Highway, the majority of first aquifer wells (assuming this is the same aquifer) are between 20 and 40 m deep, with a greater percentage of second and third aquifer wells at depths of up to 170 m. The significant reduction in shallow wells (< 20 m deep) inland of State Highway 1 is related to a deepening of the water table (generally greater than 10 m depth) inland of State-Highway 1.

In addition there were approximately 100 proposed wells as of May 2006 (Figure 1.11). 70 of these wells are proposed for irrigation and most are located inland and west of the former Hinds

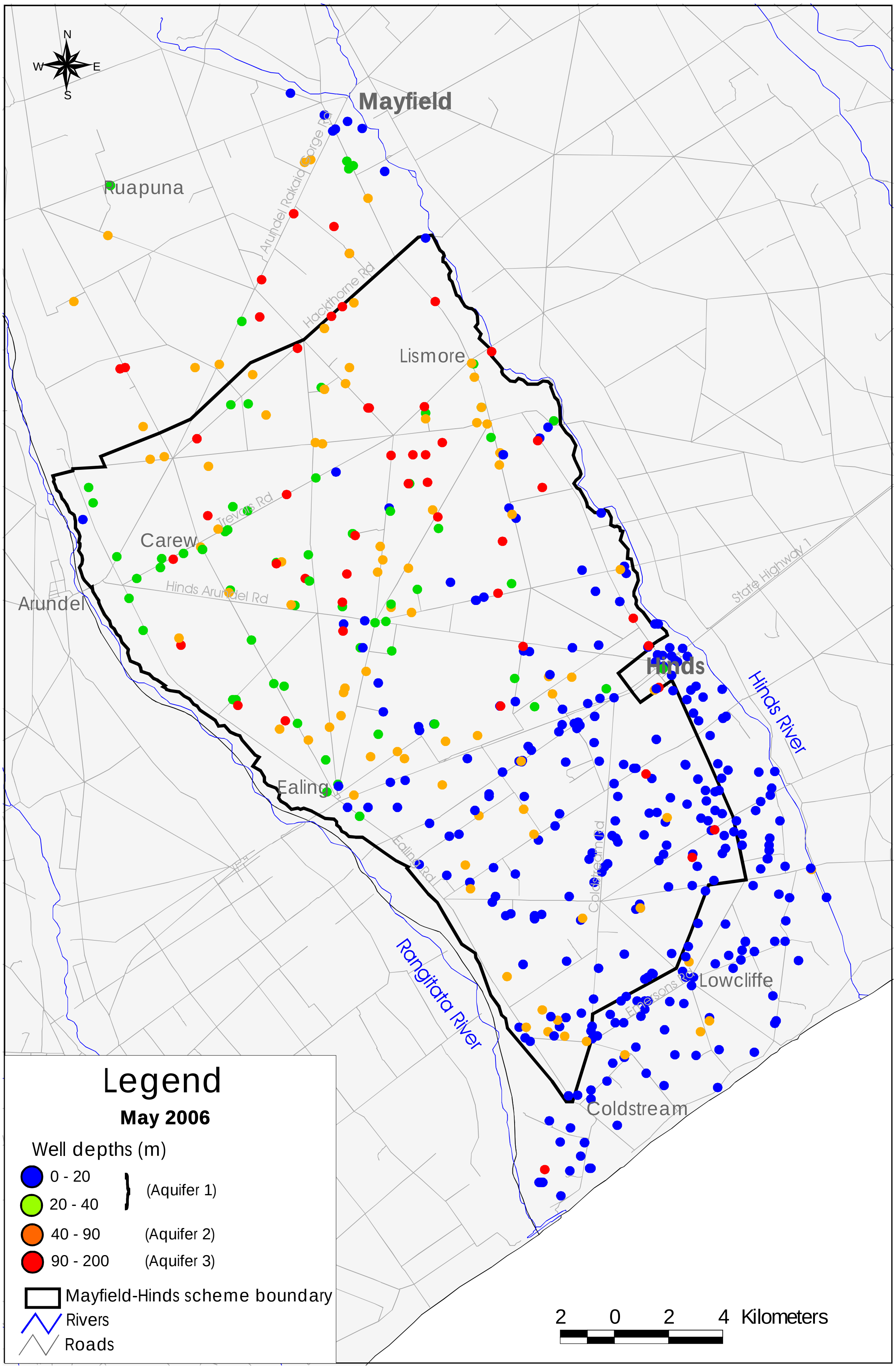

Figure 1.10 - Spatial and depth distribution of wells within the Hinds Rangitata Plain.

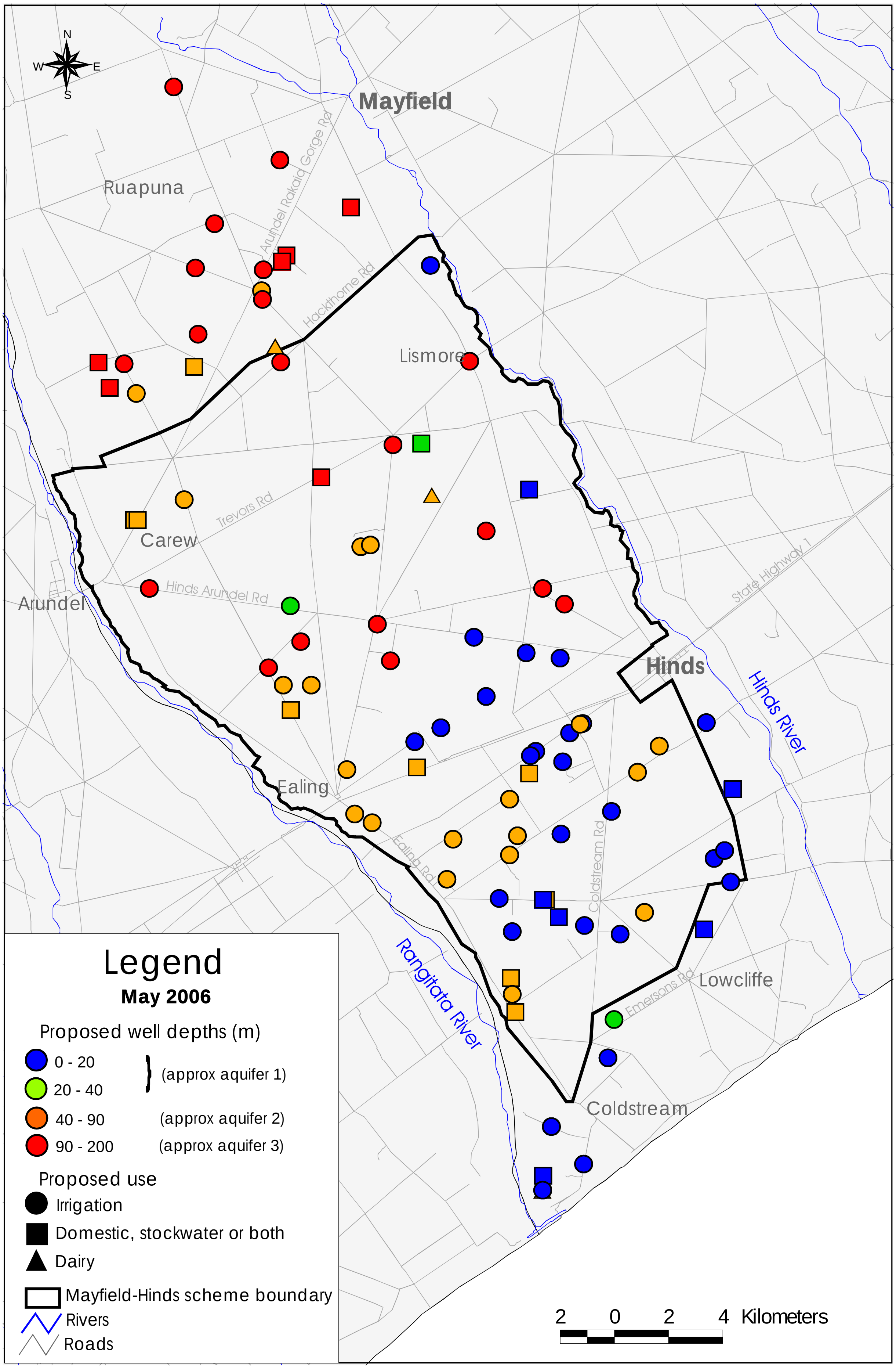

Figure 1.11 - Spatial and depth distribution of proposed wells, and the proposed uses.

Swamp. East of the State Highway, the commonly proposed depths are either 0 – 20 m (aquifer one) or 40 - 90 m (aquifer two). Inland of the State Highway, the commonly proposed depths are either 40 – 90 m (aquifer two) or 90 to 200 m (aquifer three). The deepest well drilled to date is 175m, thus it is currently unknown whether water at 200 m depth is available, and if so at what quantities? The deepest well drilled to date is 175 m. Of note is the considerable number of proposed wells in aquifer three, up-gradient of the Mayfield-Hinds Scheme. Currently there is very little groundwater abstraction from aquifer three at this location.

1.6 Irrigated Areas within the Hinds Rangitata Plain

The following information as of the 2005/06 irrigation season, was sourced from Dodson (2006). Coastward of Hackthorne Rd (Figure 1.12) the Hinds Rangitata Plain consists of 45,000 ha, with a calculated effective area (area that can potentially be irrigated) of approximately 42,000 ha. Of the effective area 35,000 ha was irrigated. Within the Mayfield-Hinds Irrigation Scheme, 21,700 ha is irrigated from border-dyke and spray (combined). Outside of the Mayfield-Hinds Scheme and east of State-Highway, 6,100 and 400 ha was irrigated from spray and border-dyke respectively. Up-gradient of the scheme, 500 – 750 ha was irrigated from groundwater sourced spray irrigation.

1.7 Mayfield-Hinds Irrigation Scheme

1.7.1 Scheme description

The Mayfield-Hinds Irrigation Scheme (shown in Figure 1.1) is the largest of three community supply schemes, including Ashburton-Lyndhurst (25,000 ha) and Valetta (7,000 ha), which take water from the Rangitata Diversion Race (RDR) for border-dyke and spray irrigation. The scheme has consent to take up to 16,140 l/s of water from the Rangitata River (via the RDR) for border-dyke and spray irrigation of up to 34,000 ha. This water is distributed from the RDR via the Main Race, 5 Laterals (Figure 1.13) and an extensive network of on-farm delivery races. At times, Laterals 4 and 5 gain flow from groundwater fed springs (Figure 1.13). The scheme covers a total area of 36,000 ha, of which 27,800 ha is contracted for irrigation. The contracted area is the area of land and corresponding water allocation as bought by shareholders in the scheme. The actual area irrigated was 19,200 ha, with 16,500 ha of border-dyke and 5,200 ha in

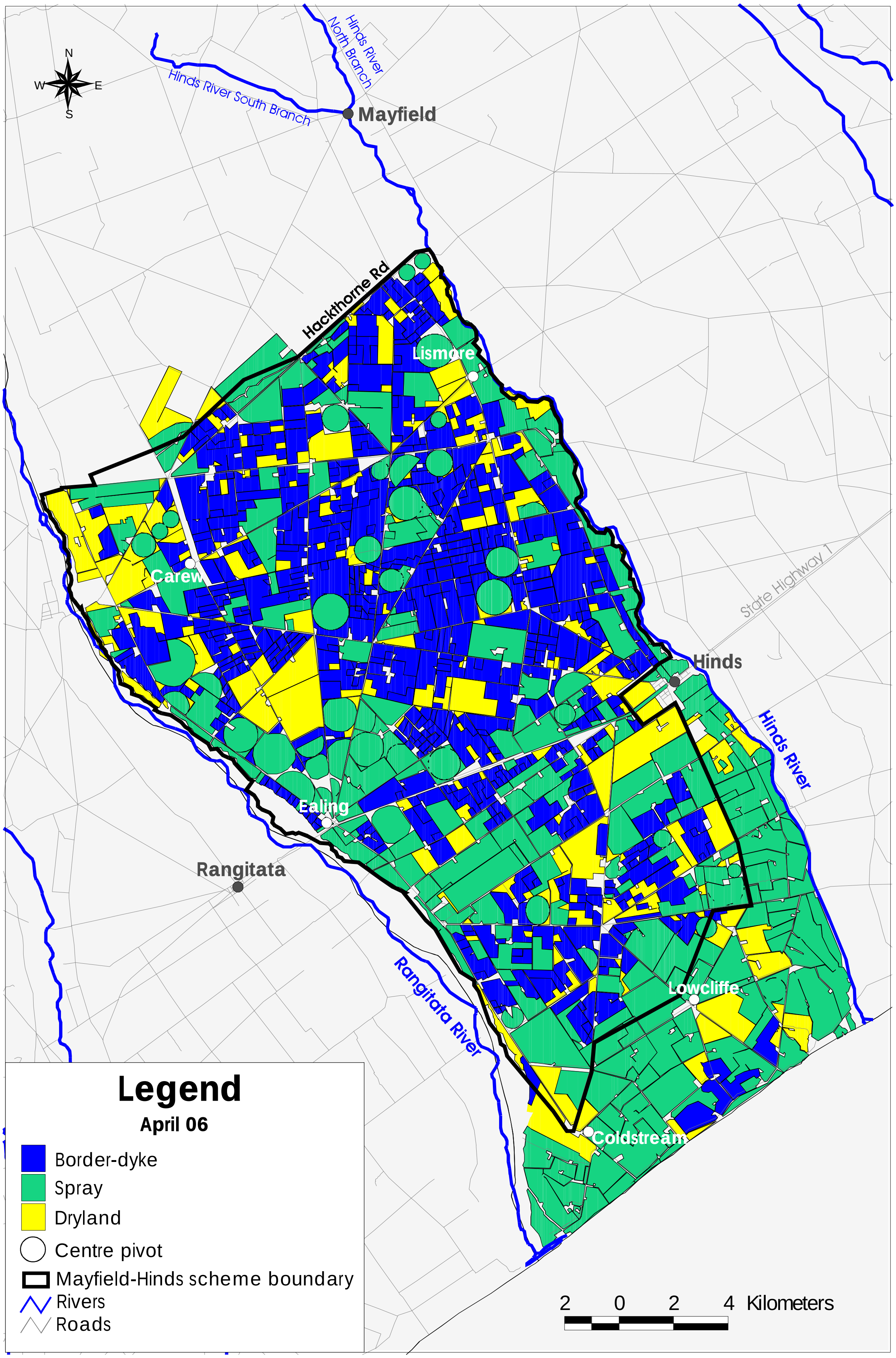

Figure 1.12 - Irrigated (spray and border-dyke) and non-irrigated land within the Hinds Rangitata Plain (sourced from Dodson, 2006).

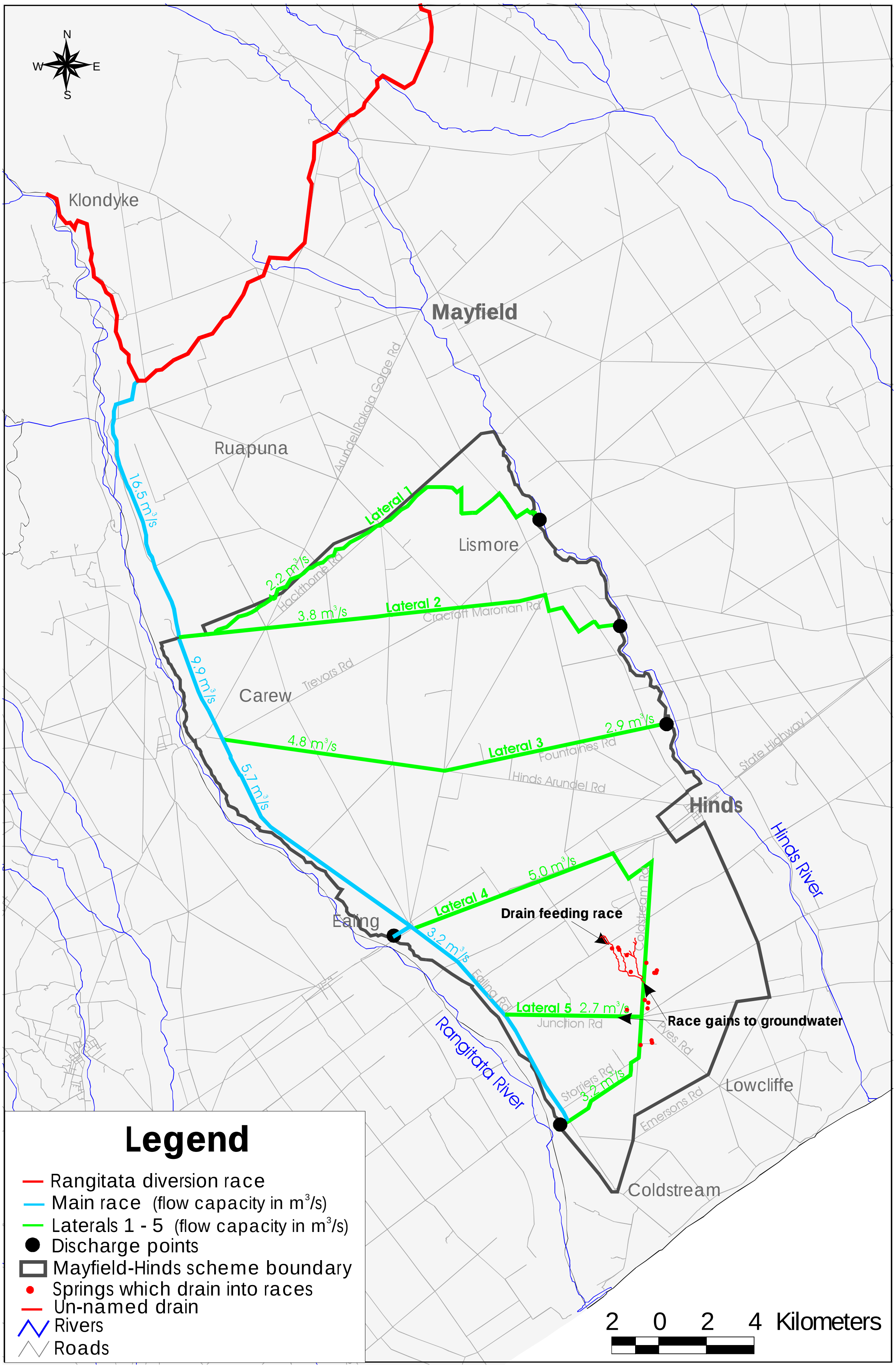

Figure 1.13 - Location of the main Mayfield-Hinds Scheme distribution races.

spray (as of the 2005/06 irrigation season). An additional 2,600 ha within the scheme was irrigated using a combination of RDR and groundwater.

1.7.2 History and developments

The original design allocation is still used by the scheme today, and provides each landowner who has shares in the scheme, with the equivalent of 12 hours of water per week at a rate of 230 l/s for 100 acres (40 ha) of land. 32,000 ha of land within the scheme are supplied with this equivalent volume of water; this is defined as the contracted area.

The scheme was originally built and operated by the Ministry of Works and Development (MWD), with water first made available for the 1948/49 irrigation season. From 1948 to 1976, water sales were slow, even compared with the other two RDR schemes (Figure 1.14).

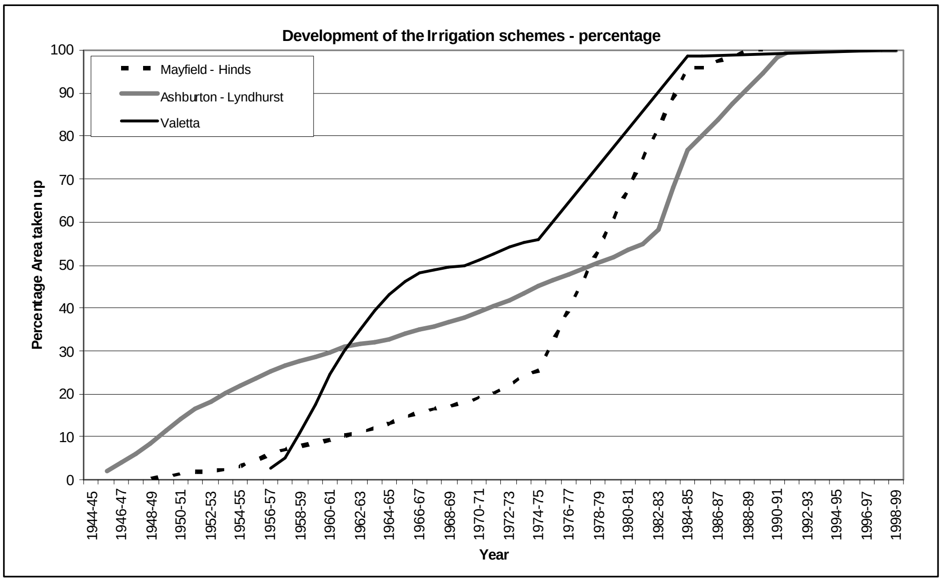

Figure 1.14 - Graph showing the percentage irrigated of the total irrigable area over time for the three RDR schemes (sourced from Vincent, 2004).

By 1976 only 20% of the scheme area was under irrigation. As an incentive to increase the rate of uptake, the MWD offered free border construction for landowners wishing to irrigate. Two main reasons for the slow uptake of irrigation include the perceived idea that dryland farming was more profitable than irrigable farming on the same soil types, and during this time most farmers only used irrigation as insurance against drought often neglecting to irrigate their land until soils had reached wilting point (Engelbrecht, 2000). Irrigation uptake was also much slower near the top of the scheme where rainfall was greater and natural soil moisture levels were higher over the summer. From 1976 onwards, more intensive farming practices lead to a rapid increase in the uptake of water and by 1985 close to 100 percent of the total irrigable area was contracted under irrigation. Since then, the irrigated area has remained relatively constant. In 1990 the Crown sold the scheme and ownership was taken from the MWD and handed over to contracted users who formed incorporated societies. Today they are known as the Mayfield-Hinds Irrigation Society. Daily management of the scheme was and still remains the responsibility of the RDR Management Ltd (RDRML), who is the present holder of the current water right consents.

The scheme was originally designed to supply five-eights (22,500 ha) of the irrigable area (36,000 ha) with 5 mm of water each day. The current seasonal maximum consented volume of 320 m^3 x 106 equates to 4.1 mm/ha/day or an average total of 1,000 mm/ha/season when applied over the entire contracted area (32,000 ha). This is greater than the average annual rainfall of approximately 750 mm within the scheme. Conventionally, it is acknowledged that to irrigate at a rate less of than 5 mm/ha/day is deficit irrigating. The average rate of evapotranspiration over summer is approximately 5 mm/ha/day, with rates as high as 7.5 mm/day not uncommon within the Mayfield-Hinds Scheme. In addition, restrictions on the water take may occur during dry periods, further reducing the application depth. Thus inadequacies in the reliability of supply, the inability to meet daily water requirements, and a shift towards higher water demanding landuses (e.g. dairying) are the main reasons why many farmers are having too, or propose too take groundwater (either as the sole source of irrigation or to supplement the scheme water).

The scheme has consent to irrigate from the 10 September until the 10 May (243 days), and irrigation cannot occur outside this period. However depending on pre season soil moisture levels, full irrigation often does not start until two or three weeks into the season. Peak water demand occurs between January and March.

Water is distributed to farms using either 10 cusec (283 l/s) or 8 cusec (227 l/s) races, however most are supplied at 8 cusecs. Seasonal water usage data between the 1980/81 and 2005/05 seasons show that the mean volume of water used is only 71% (varies between 47 – 95 %) of the maximum consented take. This is partly due to water restrictions which occur for approximately

50% of the season. Generally the scheme will receive its full allocation for only 36 days. Restrictions occur as a result of low flow conditions in the Rangitata River.

A notable trend over the last 10 – 15 years has been the increased efficiency of irrigation, mainly brought about through re-bordering and border-dyke conversion to spray irrigation. In addition, many shareholders are now spray irrigating from ponds, filled with either RDR water or a combination of RDR water and groundwater. Thus despite the contracted area remaining unchanged since 1985, many farmers within the scheme are now irrigating more land with the same volume of water. As improvements in efficiency enable farmers to irrigate more land with the same volume of water, groundwater recharge from the scheme will be reduced.

1.7.3 Affects on the water resources

Most of the irrigation water not stored within the crop root zone enters the groundwater system. In contrast to spray, border-dyke irrigation methods apply greater quantities of water than what the soil can hold, resulting in significant groundwater recharge. Within the Mayfield-Hinds Scheme (and in other selected locations), this recharge water causes groundwater levels to rise, and increases the flow from springs and groundwater fed drains. This recharge water is then used by groundwater and surface water abstractors (from the drains and the Hinds River) for irrigation, and by many landowners for domestic and stockwater purposes. Of some concern is that improved irrigation efficiency will result in less groundwater recharge, reducing the quantity of water available for irrigation and other needs.

1.8 Previous Work

The earliest hydrogeological research on the Hinds Rangitata Plain was carried out by Oliver (1946 a – c). Oliver characterizes the nature and occurrence of aquifer one (0 – 20 m deep) for much of the Ashburton County, with particular reference to the Hinds Rangitata Plain area coastward of State-Highway 1. The work was carried out to better manage drainage problems within the former Longbeach-Hinds Swamp area, give advice on the digging of new drains, to better understand the nature and occurrence of springs, and to determine the affects of irrigation seepage on down-gradient groundwater levels.

Mitchell (1980) provides a history of the Ashburton – Hinds drainage district. The drainage network is discussed in relation to the hydrogeology, the influence of large rainfall events, drainage history and the issues related to maintenance and improvements.

Between 2000 and 2002, three reports were written on the affects of irrigation recharge on groundwater levels and groundwater quality from the three Rangitata Diversion Race Irrigation schemes (of which the Mayfield-Hinds Scheme is one). Environmental Consultancy Services (2000) discuss the affects of the Rangitata Diversion and the Mayfield-Hinds Scheme on groundwater levels. Pattle Delamore Partners (2002 a) also discuss the affects of irrigation recharge from each RDR scheme on groundwater levels and drain flows. In addition Pattle Delamore Partners (2002 b) discuss the affects of irrigation on groundwater quality within and adjacent to each of the three RDR schemes.

The most recent work on the Hinds Rangitata Plain was carried out by Davey (2003, 2005, 2006 a – b). Davey (2003) reported on the nature and occurrence of springs, characterizing the different types, defining unique zones and commenting on the likely sources of recharge. Davey (2005) reported on the drilling of three monitoring wells near Hinds Township. The report provides some of the best evidence for three distinct aquifers (and the likely thickness) occurring within this area. Davey (2006 a) discuss the aquifers in this area, describing them in terms of their geology and hydrogeology. Davey (2006 b) reinterprets existing literature and former theories on the depositional and post-depositional process which occurred during the deposition of gravel deposits that aquifer one occur within. The report provides a new model for the nature and occurrence of aquifer one, based largely on coastal cliff and shingle pit outcrops, landowner reports and drillers logs.

1.9 Thesis Format

The thesis is presented in nine chapters.

- Chapter two describes the geology and geomorphology of the Quaternary fan deposits.
- Chapter three discusses the hydrogeology in terms of aquifer identification, nature and occurrence of aquifers one, two and three, seasonal fluctuations in water levels and groundwater flow direction.

- Chapter four discusses the seasonal fluctuations in aquifer one, factors which effect water levels and the likely sources of recharge both spatially and with depth.
- Chapter five discusses the seasonal fluctuations in aquifers two and three, factors which effect water levels and the likely sources of recharge both spatially and with depth.
- Chapter six discusses the surface water and spring resources of the area, and includes a detailed discussion of the flow regime and sources of flow within the Hinds River.
- Chapter seven presents a regional water balance, and discusses the various recharge and discharge components of the Hinds Rangitata Plain.
- Chapter eight discusses the hydrochemical facies of both the surface water and groundwater resources in order to identify sources of recharge for different areas of the plain.
- A summary of the data from chapter two through to chapter eight and recommendations for future research are presented in chapter nine.

Chapter Two

Geology and Geomorphology

2.1 Introduction

This chapter outlines the geology and geomorphology of the Hinds Rangitata Plain. The geology section discusses the geological history of the Hinds Rangitata Plain from the late Paleozoic to the late Quaternary. The geomorphology section discuses the late Quaternary depositional history, surficial gravel characteristics, fluvial, post-depositional and limonite (ironstone) influences on aquifer hydrogeology.

2.2 Geological Setting

The Canterbury plains occupy the land area from Waipara to Timaru and from the coast to the foothills (Figure 1.1). Basement rocks (underlying the Hinds Rangitata Plain) are Late Paleozoic to Mesozoic in age, and consist of Torlesse Supergroup greywacke, produced from the deposition of thick sand and clay that were subsequently eroded to produce a low relief landform (Brown, 2001). These are overlain by early trangressive marine sequences (limestone) that formed as the sea moved westward over the low-lying landscape (Brown, 2001). During the Late Tertiary (28 - 5 Ma), sandstone, siltstone, greensand, conglomerate, quartz gravel, coal measures, and limestone were deposited during a period of slow alpine uplift causing an eastward shift of the shoreline. Erosion has removed much of this sequence from the foothills and alpine areas, allowing Quaternary deposits, including glacial, fluvial and colluvial sediments to rest directly on Torlesse Basement (Barrell et al, 1996). In the Hinds Rangitata Plain gravels, red and green volcanic clasts from the Mt Somers Volcanics are commonly described at depth in the drill logs. The presence of these clasts shows that volcanics were eroded during gravel formation. In two examples, wells K37/1679 (88 m deep) and K37/1500 (172 m deep) describe the occurrence of red stones from 50 to 172 m. The location of the two wells is shown in Figure 2.1.

During the Kaikoura Orogeny (Pliocene to Mid Pleistocene) developing tectonic activity and uplift of the Southern Alps produced thick deposits of fluvial Kowai Formation gravel with

large amounts of sand, silt and clay. These sediments were deposited by eastward-flowing rivers into a basin upon folded and faulted Torlesse basement rock that connected the Canterbury Plains to the volcanic landmass (Brown, 2001). Uplift of up to 10 mm a year continued through the Quaternary with successive gravel units produced, and locally eroded, during alternating glacial and interglacial periods. Late Cretaceous, Tertiary and Quaternary sediments that overly basement, are approximately 1 km thick under much of the Rangitata fan (Hicks, 1989). The Ealing-1 oil exploration bore (K37/1225) located 5 km NE of the Rangitata River (Figure 2.1) was drilled to1696 m where it stopped in Tertiary claystone. Glacial outwash gravels occurred to a depth of 637 m, the greatest thickness of outwash gravels recorded on the Canterbury Plains (refer to bore log in Appendix 2.1). Elsewhere on the plains, gravel thicknesses of 545 m (Seafield), 413 m (Chertsey) and 355 m (Brookside) show that the thickness of alluvial gravels is variable. Loess is thin (<0.5 m) or absent on most of the fan (Ives, 1972).

2.3 Hinds Rangitata Plain late Quaternary Depositional History

2.3.1 Rangitata and Ashburton Rivers

The majority of the Hinds Rangitata Plain was formed during the Late Quaternary (approximately 400,000 years ago to present). During glacial periods large glaciers occupied the Rangitata and Ashburton river valleys, extending to the eastern edge of the foothills (Barrell et al, 1996). During these times erosion rates increased due to reduced vegetation cover, and increased mechanical weathering of greywacke by ice, snow and water. This resulted in the eastward transport of gravel, sand and silts from glacial feed rivers to form a series of large coalescing outwash fans on the lower plains. Variation in the lateral extent of the Rangitata and Ashburton rivers during glacial periods resulted in the complex overlapping of successive outwash fans. However, during periods of glacial maxima it is likely that the less extensive Ashburton River constructed a narrow (approximately 6 – 10 km) sector of plain restricted between the adjacent (topographically higher) alpine Rangitata River and Rakaia River fans (Brown, 2001). The smaller Hinds River, with its 350 km^2 unglaciated catchment, occupied the depression between the two larger Rangitata (1600 km^2 catchment) and Ashburton (4000 km^2 catchment) River fans (Brown, 2001).

During the Waimean (penultimate) glaciation outwash from the Rangitata River may have extended from the Ashburton River to the Opihi River (Brown, 2001). In periods of glacial maxima, flow from the Rangitata River was reduced when distributary lobes of the Rangitata glacier discharged into the South Ashburton River (Barrell et al, 1996). Glacial outbursts and possible landslide dam break floods causing large scale flood events have been postulated for the occurrence of boulders at the land surface and at depth below the plains. The Rangitata River is currently on the southwestern side of its fan during the last glaciation (Brown, 2001).

During interglacial and the present post glacial period, the glaciers retreated, and vegetation established to higher altitudes resulting in lower rates of erosion. In addition, evidence suggests that a lake occupied the former glacial trough left behind after glacial retreat in the Rangitata River valley. This would have acted a sediment trap for gravel and sand but not fine sediment, further reducing sediment delivery to the Rangitata River and increasing the rate at which the Rangitata River incised into its fan (Barrell et al, 1996). Reduced sediment loads and tectonic uplift caused the Rangitata and Ashburton Rivers to entrench into there former glacial outwash deposits up to 40 km downstream from the foothills (Leckie, 1994). Coastal retreat from a high energy wave environment caused a zone of coastal incision up to 15 km inland. This occurred as the river cut down to sea level, thus incising into its fan (Leckie, 1994). Between the two zones of incision was an area of minimal erosion (10 – 15 km long) where the river was only slightly incised into its fan. Currently the height of the river terrace in this zone of minimal erosion is 1 – 2 m above the bed of the Rangitata River (Browne, 2002).

2.3.2 Hinds River

In contrast, the Hinds River was not a fan building river, instead reworking sediment originally laid down by the Rangitata and Ashburton Rivers and depositing silt, clay and fine swampy detritus material within the depression between the Rangitata and Ashburton Rivers (Mitchell, 1980). However, during the Otiran glaciation, water from the South Ashburton River joined the Hinds River from the vicinity of Mt Somers, increasing the quantity of sediment transported and deposited by the river (Barrell et al, 1996). In general, sedimentary deposits associated with the Hinds River are locally fine and better sorted than those associated with the Rangitata River

(Oliver, 1946 c). During postglacial times the Hinds River originally flowed into a swamp half way between Boundary and Surveyors Roads (shown in Figure 6.1). At this time the current Boundary Drain (shown in Figure 6.3) acted as its natural outlet channel to the sea. Bacterial processes within this swampy area are believed to have resulted in the formation of ironstone formations with distinctly lower permeability than the adjacent gravel fans (Sanders, 1996). Between 1867 and 1903, this swampy area was drained (using open drains and tile drains) for farming, and a direct channel was cut allowing the Hinds River to flow to the sea. Since then headward erosion from a regressing coastline has caused the river to incise from approximately 4 km inland to the coast (Wilson, 1985).

2.4 Stratigraphy

2.4.1 Accepted nomenclature

Five major glacial advances have been recognized in the Rangitata River valley through the identification of glacial moraines and other morphological features (Table 2.1). Aggradational outwash surfaces associated with these glacial advances have been traced onto the plains, and a nomenclature to describe these gravel deposits and compare them with climatic events determined. For the Rangitata River valley, this has been carried out by Mabin (1980), Oliver & Keene (1989), Oliver & Keene (1990) and Barrell et al (1996). Although inland plains gravel deposits are recognizable in the field by characteristics such as color, degree of weathering and sorting, it is almost impossible to extrapolate these units underground because erosion intervals cannot be recognized from bore log descriptions (Vincent, 2005).

2.4.2 Plains gravel deposits

Gravel deposits between the Opihi and Ashburton Rivers are predominantly glacial outwash, deposited by the Rangitata River (Figure 2.1). With the exception of the Ashburton River, current-post glacial gravels are generally restricted to river margins (Figure 2.1). Within the Hinds Rangitata Plain, Gair (1967) and Suggate (1973) divide the major gravel deposits into Windwhistle, Burnham and Springston Formations (Figure 2.2). Burnham Formation glacial outwash gravel deposited by the Rangitata River during the Late Otiran glaciation (24,000 – 14,000 years before present) covers most of the area. A small area of Windwhistle Formation

Table 2.1 - Nomenclature and correlations between late Quaternary glacial advances and plains surface gravel deposits.

International Series: Period	International Series: Epoch	New Zealand Series: Climatic Stage	Years before present	Christchurch Coastal Units[1]	Christchurch[2]	Rangitata River[3]: Plains Deposits	Rangitata River[3]: Glacial Advances	Rangitata River[4]: Plains Deposits	Rangitata River[4]: Glacial Advances	Rangitata River[5]: Rangitata RG	Rangitata River[5]: Sth Ashburton SA	Deposits[5]
QUATERNARY	HOLOCENE	Aranuian	14,000	Christchurch Springston	Christchurch Springston	Recent Springston	No advance	fa	No advance	RG0 RG1 RG2	SA1	Grey Gravels
QUATERNARY	PLEISTOCENE	Otirian	24,000	Riccarton Gravel	Burnham	St Burnard Burnham	Spider Lakes Hakatere	St Burnard Burnham	Spider Lakes Hakatere	RG3 RG4	SA2	Grey-Brown Gravels
QUATERNARY	PLEISTOCENE	Otirian	59,000	Riccarton Gravel	[6]	[6]	[6]	[6]	[6]	[6]	[6]	Grey-Brown Gravels
QUATERNARY	PLEISTOCENE	Otirian	73,000	Riccarton Gravel	Windwhistle	Windwhistle	Trinity Hill	[6]	[6]	RG5	SA3	Grey-Brown Gravels
QUATERNARY	PLEISTOCENE	Kaihinu	128,000	Bromley	[6]	[6]	[6]	[6]	[6]	[6]	[6]	Brown Gravels
QUATERNARY	PLEISTOCENE	Waimean	188,000	Linwood Gravel	Woodlands	Woodlands	Dogs Hill	[6]	[6]	[6]	SA4	Brown Gravels
QUATERNARY	PLEISTOCENE	Karoroan	241,000	Heathcote	[6]	[6]	[6]	[6]	[6]	[6]	[6]	Brown Gravels
QUATERNARY	PLEISTOCENE	Waimaungan	291,000	Burowood Gravel	Hororata	Hororata	Pyramid	[6]	[6]	[6]	[6]	Brown Gravels
QUATERNARY	PLEISTOCENE	Scandanavian	350,000	Shirley	[6]	[6]	[6]	[6]	[6]	[6]	[6]	Brown Gravels
QUATERNARY	PLEISTOCENE	Nemonian	380,000	Wainoni Gravel	[6]	[6]	[6]	[6]	[6]	[6]	[6]	Brown Gravels
QUATERNARY	PLEISTOCENE	Early Glacial / Interglacial	1.2 Ma	Kowai	[6]	[6]	[6]	[6]	[6]	[6]	[6]	
TERTIARY		Porikan	2.2 Ma	Kowai	[6]	[6]	[6]	[6]	[6]	[6]	[6]	
TERTIARY		Ross	2.5 Ma	Kowai	[6]	[6]	[6]	[6]	[6]	[6]	[6]	

Key

1 Brown & Weeber, 1992
2 Suggate, 1973
3 Mabin, 1980
4 Oliver & Keene, 1989 & 1990
5 Barrell, Forsyth & McSaveney, 1996
6 Deposits not present or unidentified

Postglacial period (Aranuian rows)
Interglacial period (59,000; Kaihinu; Karoroan; Scandanavian rows)
Glacial period (Otirian; 73,000; Waimean; Waimaungan; Nemonian rows)

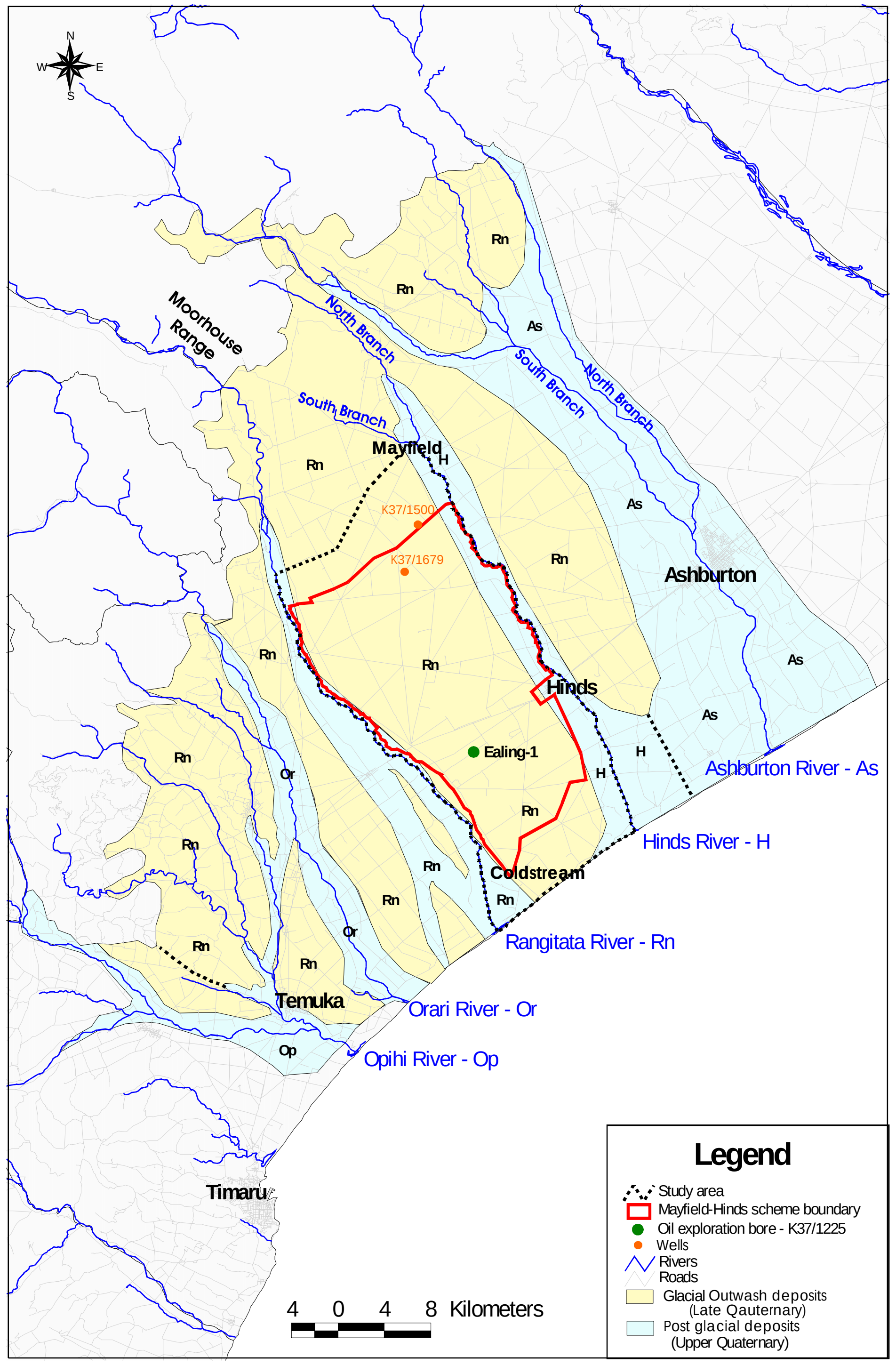

Figure 2.1 - Glacial and post glacial fan deposits of the Opihi, Orari, Rangitata Hinds and Ashburton Rivers (source: Institute of Geological and Nuclear Sciences, 2001). The location of Ealing-1 oil exploration bore and two wells from which Mt Somers volcanic rocks were recorded are also shown.

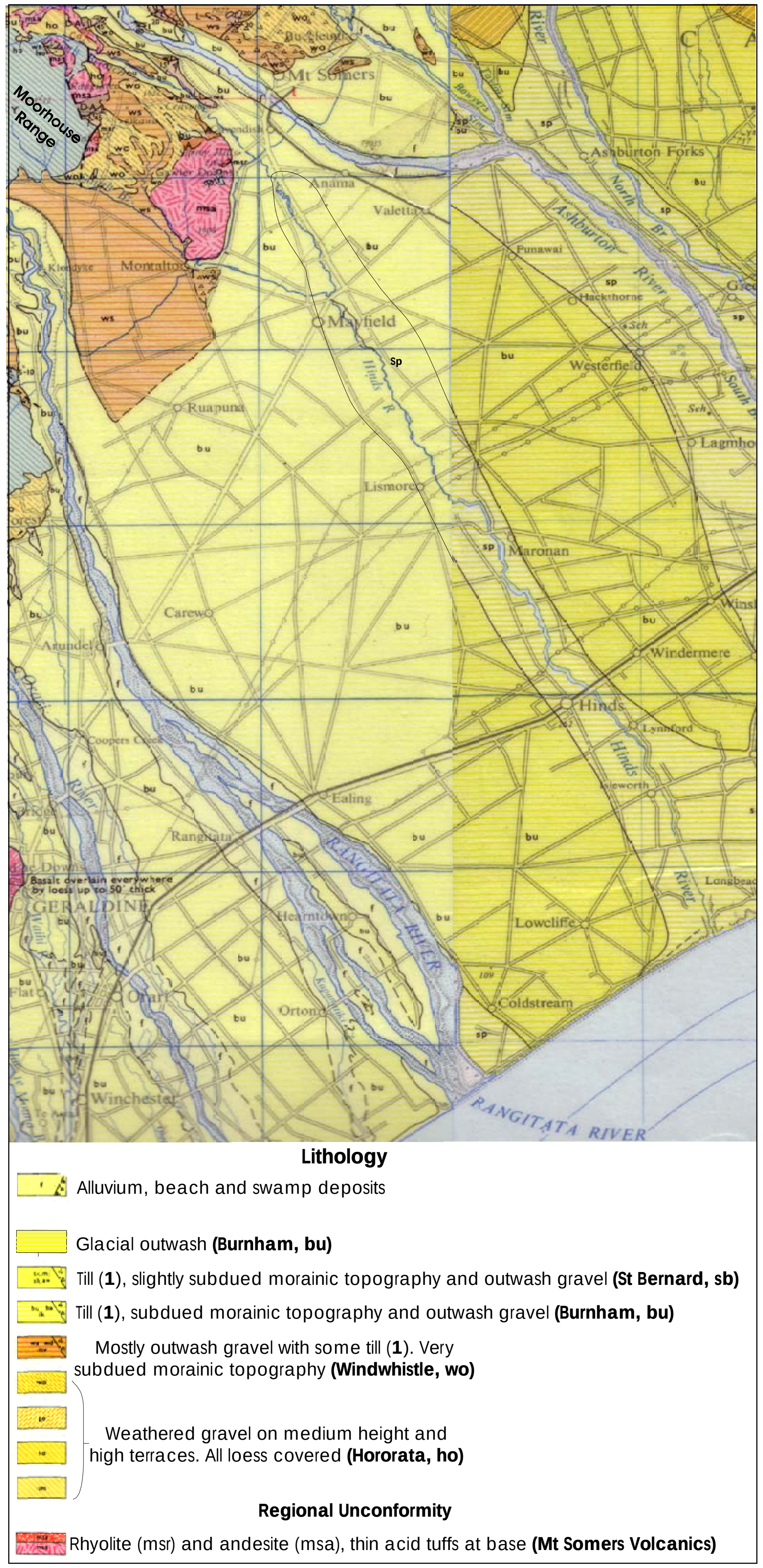

Figure 2.2 - Geological map of the Hinds Plains (Gair, 1967 and Suggate 1973).

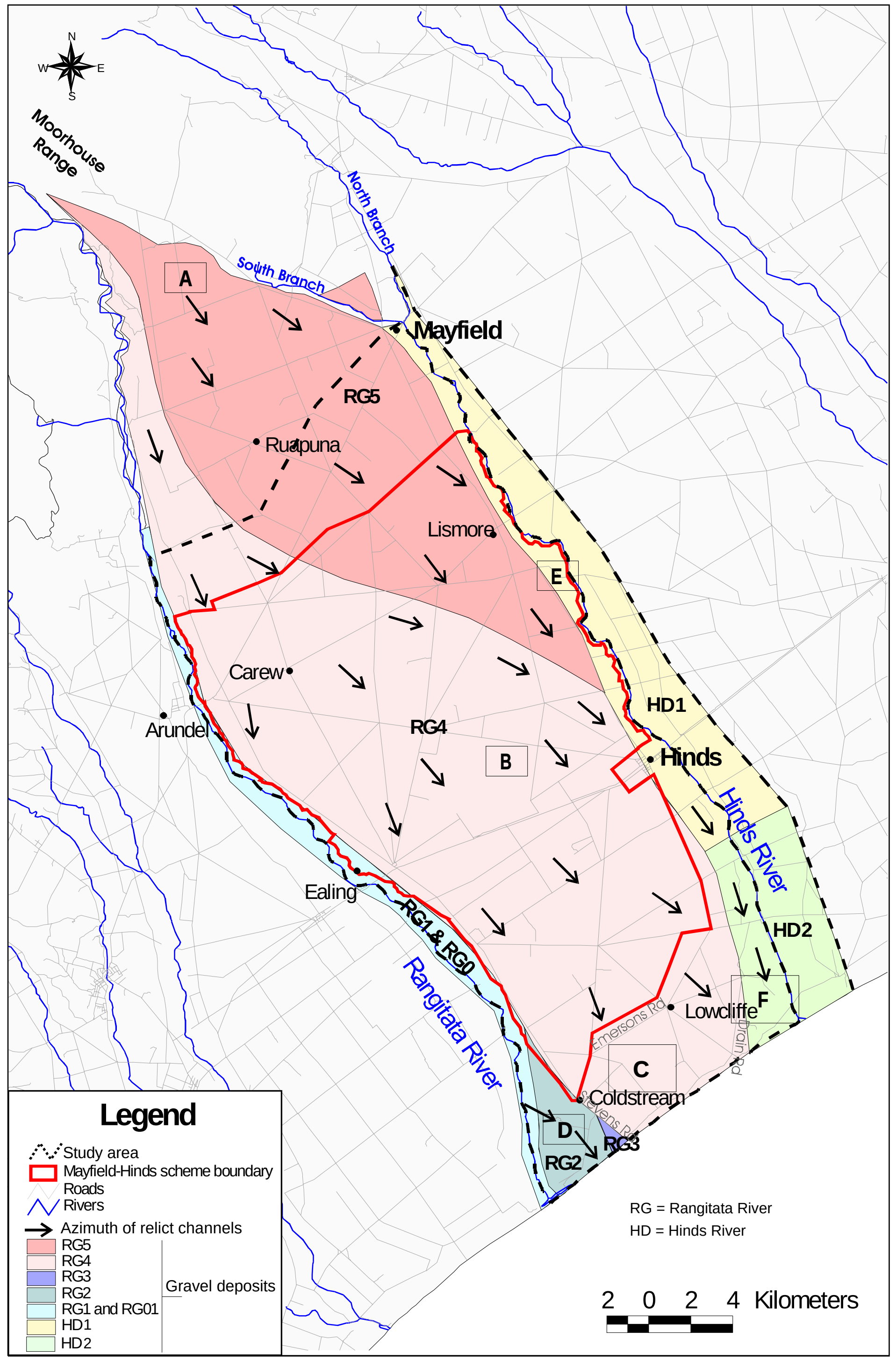

Figure 2.3 - Surface geology of the Hinds Plains. The Rangitata River fan (RG) is divided into five groups, RG5 (oldest) to RG0 (youngest). The Hinds River fan (HD) is divided into two groups, both post glacial in age. Black arrows show the azimuth of relict channels (source: modified from Barrell et al, 1996). Squares A - F refer to photos discussed in the text.

outwash gravel deposited by the Rangitata River during the Early Otiran glaciation (73,000 – 59,000 years ago) extends coastward from the Moorhouse Range to approximately 1 km inland of Ruapuna (Figure 2.2). Post-glacial Springston Formation sediments deposited by the Rangitata River occur at the coast near Coldstream (Figure 2.2), whilst a narrow (approximately 2 km) strip of Springtson Formation sediment derived from the Hinds River extends coastward approximately Mayfield Township. Barrell et al (1996) provides the most current and detailed geormorphic description of the gravel deposits in this area (Figure 2.3). A brief description of their work with additional information obtained from historic aerial photographs is provided below.

2.4.3 Rangitata Fan surface

Gravels of the Rangitata Fan are predominantly derived from greywacke, with minor quantities of volcanic rock and limestone. Most of the greywacke gravel is either massive or poorly stratified with a silty sand matrix and the maximum size of the coarsest fraction decreases down-stream (Barrell et al, 1996). Relict channels are generally parallel to the modern day river courses (Figure 2.3). The Rangitata Fan is divided into five units, RG5 (Oldest) to RG0 (youngest). A photo of the surface channel features is provided in the discussion for each unit. The location of each photo is shown in Figure 2.3.

RG5

RG5 gravels (correlated with the early Otiran glaciation) extend coastward from the Moorhouse Range close to the Rangitata River, then taper in towards the Hinds River, terminating approximately 4 km inland from Hinds Township. The surface pattern is characterized by low relief anastomosing braided river channels, similar to those occurring today in the active channels of the lower Rangitata River (Figures 2.3 (square A) and 2.4). Stones greater than 8 cm diameter are common and the gravels consist of hard, slightly weathered clasts exhibiting weathering rinds and clay coatings. Clasts occur within a brown matrix of slightly to moderately cemented sand, silt and clay with minor iron oxide coatings.

Figure 2.4 - Braided Rangitata River channels on the RG5 fan surface. Yellow arrows show palaeo flow direction. Square A, shown in Figure 2.3.

RG4

RG4 gravels (correlated with the late Otiran glaciation) extend from the Moorhouse Range to the coast. Aerial photographs show the Rangitata Fan sloping down-gradient from Rangitata River NE towards the Hinds River (Appendix 2.2 a). From the middle of the Rangitata Fan to the Hinds River the fan gradient is near horizontal (Appendix 2.2 a). Downstream of Arundel the RG4 surface is extensive, representing a period of ice advance when the Rangitata River was at grade or aggrading. The surface pattern is characterized by braided river channels, similar to those occurring today in the Rangitata River (Figures 2.3 (square B) and 2.5). Gravel clasts which are well exposed in sea cliffs (between the Hinds and Rangitata Rivers) are poorly sorted, hard, un-weathered to slightly weathered and iron-stained (clast-on-clast points are unstained). Many clasts are coated in light yellow clay, thought to have been derived from the overlying loess and soil, not from in-situ chemical weathering. The matrix is a slightly too moderately iron-stained silty matrix and weakly iron or clay cemented in some places. Gravel and sand often in the form of lenses, generally make up less than 25% of the deposits.

Figure 2.5 - Braided Rangitata River channels on the RG4 fan surface. Yellow arrows show palaeo flow direction. Square B, shown in Figure 2.3.

During the intervening interglacial period between RG5 and RG4, the Rangitata River incised significantly more into the head of the fan (inland from Arundel) in contrast to the lower section of the fan (downstream of Arundel). This caused the younger RG4 aggradation surface to be entrenched within the incised section of RG5. This is why topographically, RG4 lies beneath RG5 inland from Arundel (refer to Figure 2.6). Coastward of Arundel, RG4 merges with and overlies RG5.

From approximately Stevens Rd to Drain Rd (Figure 2.3), 3 km inland from the coast, RG4 surface gravels are cut by numerous sinuous channels (Figure 2.6 and Appendices 2.2 b - d). These channels occur within and slightly coastward of a dense belt of depression springs (shown in Figure 6.1) which occur on or close to natural gullies (Davey, 2003). These channels were likely formed by a combination of surface water runoff, spring flow erosion of the fan surface or as prior relict Rangitata River channels on the surface of the fan (Davey, 2003). Aerial photographs also show that the fan surface 3 – 4 km inland from the coast is marked by a number of depressions spaced at approximately 2 – 5 km intervals (Appendix 2.2 b). These depressions and the joining up of channels towards the coast likely form small catchments which feed groundwater and surface runoff into the drains. These drains incise down through the coastal cliffs where they discharge into the sea or seep through a gravel bar into the Pacific Ocean.

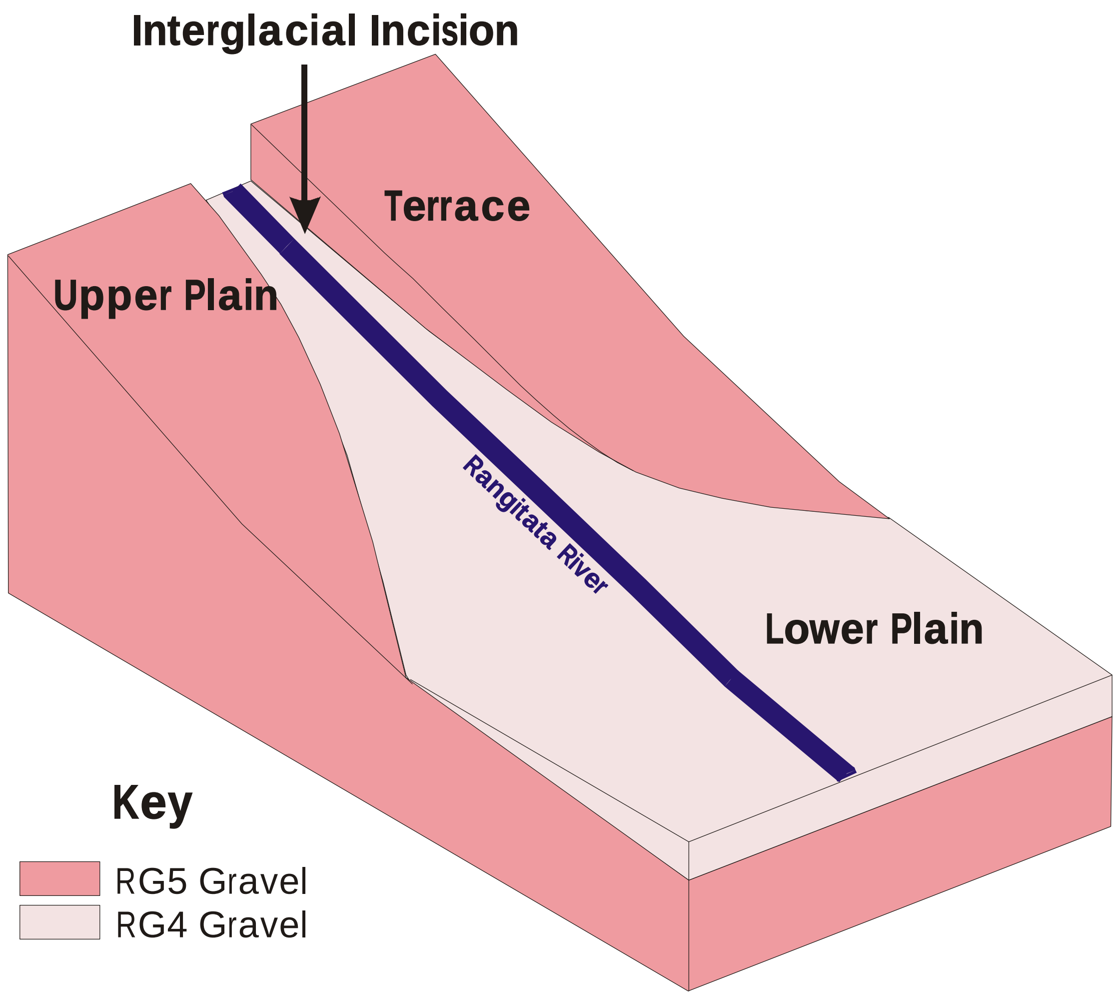

Figure 2.6 – Schematic diagram showing the relationship between RG5 and RG4 gravel deposits.

RG3

RG3 gravels occur in a small area coastward of Coldstream (Figure 2.3) and are correlated to a later period of aggradation (compared to the earlier aggradation forming RG4) during the Late Otiran (Table 2.1). Clast composition and matrix are the same as RG4. Barrell et al (1996) does not describe these gravel deposits in any more detail.

RG2

RG2 gravels occur in a fan shaped area between Coldstream and the Rangitata River and are interpreted as late Otriran to early Aranuin in age. Remnant channels are generally finely braided and smooth, and emanate (spatially) in a north easterly direction out from the Rangitata

River north bank near Coldstream (Figures 2.3 (square D) and 2.7). Aerial photographs show that the RG2 fans slopes downwards from the Rangitata River to Coldstream, where it forms a small depression at the contact with RG3 and RG4 surface gravels (Appendix 2.2 c and d). Clast composition and matrix are similar to RG4. Barrell et al, (1996) suggest these deposits may have been the product of rapid aggradation following a dam break flood event.

Figure 2.7 - Braided Rangitata River channels on the RG2 fan surface. Yellow arrows show palaeo flow direction. Square D shown, in Figure 2.3.

RG1 and RG0

RG1 is a degradational surface produced during the postglacial period, and occurs adjacent to the Rangitata River. Channels are deep and anastomising. RG0 represent modern day river deposits. Clasts for both RG1 and RG0 are hard, grey, unweathered and occur within an un-cemented sandy matrix.

2.4.4 Hinds Fan surface

<u>HD1</u>

The Hinds River Fan, from Mayfield Township downstream to Surveyors Rd, shows evidence of braided channels, however visible surface features are dominated by single deep channels (Figures 2.3 (square E) and 2.8). Overall, channel features are less visible than on the Rangitata fan. One reason could be land alteration through farming practices, however such farming practices were likely occurring over other parts of the Hinds Rangitata Plain. In conclusion, it is likely that the Hinds River deposited gravel in a narrow braided river bed; with the flow often concentrated to single large channels. The increased soil water holding capacity close to the Hinds River, suggests that channel avulsion during flood events and subsequent deposition of fine over-bank sediments was common.

Figure 2.8 – Remnant Hinds River channels on the HD1 fan surface. Yellow arrows show palaeo flow direction (Map source: NZ Aerial Mapping Ltd, 1952). Square E, shown in Figure 2.3.

<u>HD2</u>

From approximately Surveyors Rd to the coast, the Hinds River fan is characterized by numerous small, narrow, sinuous and meandering channels (Figures 2.3 (square C) and 2.9).

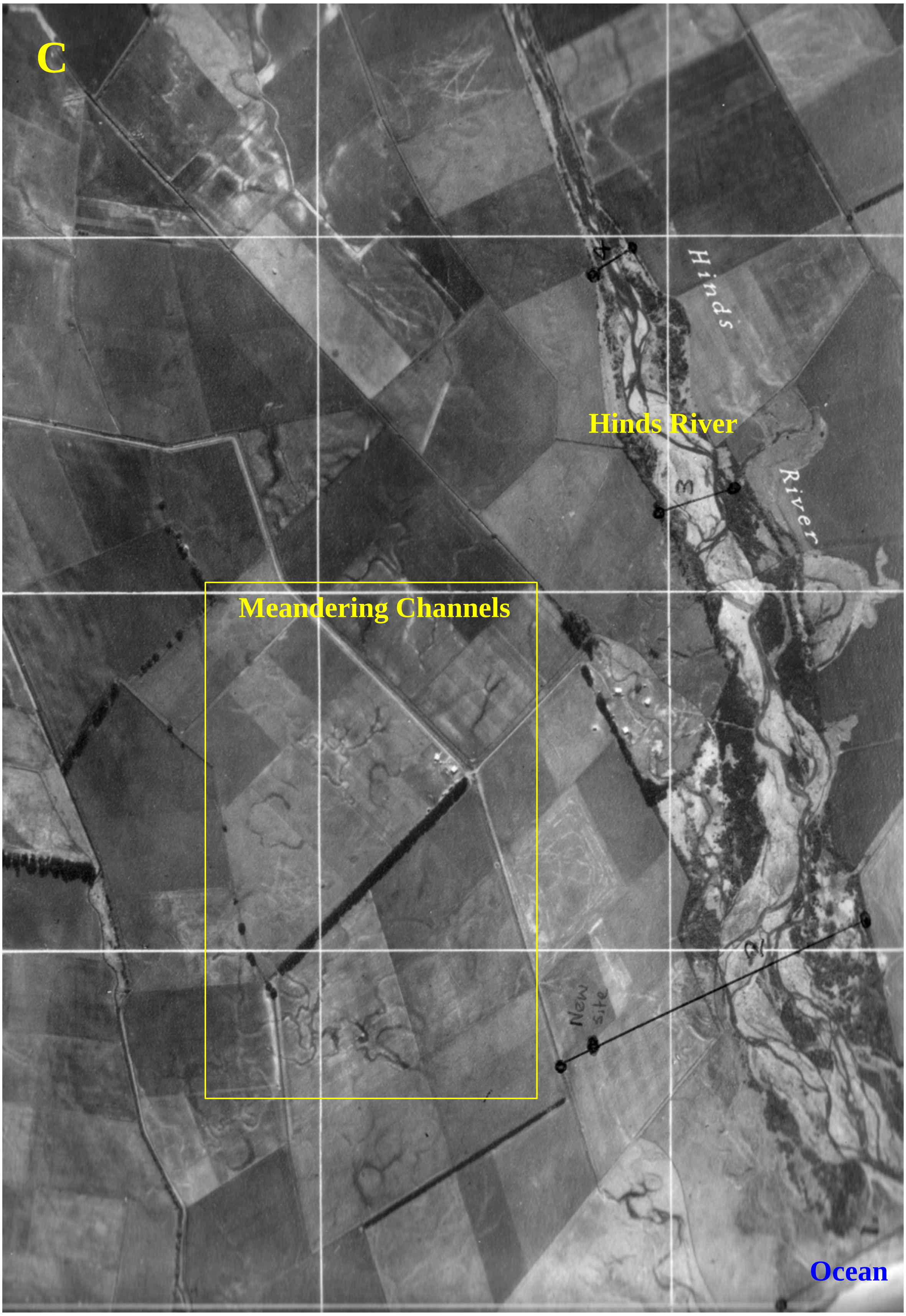

Figure 2.9 - Remnant Hinds River channels on the HD2 fan surface. Meandering channels within the old Hinds swamp are shown in the yellow box (source: NZ Aerial Mapping, 1954). Square C, shown in Figure 2.3.

These relict channels are orientated in a more SW direction compared with relict Rangitata River channels (Figure 2.3). Prior to cutting the artificial channel, the Hinds River flowed into a swamp halfway between Boundary and Surveyors Rd. If a majority of the Hinds River flow was distributed amongst the natural gullies and depressions within this swampy area, then this could explain the absence of braided or single dominant channels. Channel features from historic aerial photographs in Appendix 2.2 a, show how remnant meandering Hinds River channels may have flowed close to the margins of the Hinds Swamp. These channels can be traced from the current Boundary Drain to approximately Mayfield Township. In contrast, the artificial channel that allows the Hinds River to flow to the sea is highly braided (Figure 2.9).

2.5 Deposition and Post-Deposition Influences on the Hydrogeology

2.5.1 Deposition and post-deposition fluvial influences

Wilson (1973) describes the progressive shifting and abandonment of river channels on the fan surface producing a complex network of more permeable channels (less fines) surrounded by less permeable over-bank deposits (more fines). Browne & Thrasher (1996) & Browne (2002) describe the formation of permeable bars and channels when fines (mud and sand) are removed by eolian processes, or washed through bar and channel deposits by interstitial river water, rainfall, or sub-horizontal groundwater soon after deposition; all are processes which occur in the beds of modern braided Canterbury rivers. Shulmeister (cited in Davey, 2006 b) believed that large remnant channels are likely to be eroded by scour and fill processes, during and post-deposition. These processes would either totally erode the channel or leave smaller remnant channels that would be preserved at depth today as relatively thin, narrow permeable lenses.

In terms of sorting, Barrell et al (1996) states that Rangitata River gravels are better sorted and finer nearer the coast. On the basis that mean grain size becomes more uniform and finer nearer the coast, gravel permeability may decrease closer to the coast.

2.5.2 Post-deposition groundwater influences

Evidence from cliff outcrop sections near Lowcliffe suggest that groundwater is actively transporting fine sediment (mainly silt) through aquifer one. Photos from Davey (2006 b) show fine sediment being actively washed through a flowing permeable lens and deposited at the base of the lens at the contact with the surrounding relatively less permeable sediment. Davey (2003) suggests the higher water table near the coast may be partly caused by fine sediment being washed from gravels in the upper plains, and deposited within gravels of the lower plains. Thus the active transport of fine sediment through the aquifer may create, enlarge or decrease the size of permeable lenses depending on whether sediment is being wash into or out of the lens, or may connect previously disconnected lenses (Davey, 2006 b).

2.5.3 Aquifer one hydrogeology

Over much of the study area, aquifer one extends from near surface to approximately 40 – 50 m. For a detailed description of the hydrogeology, refer to Chapter 3. From shingle pits (up to 32 km inland), galleries, sea cliff outcrops, drain cuttings, and Rangitata River Terrace springs, highly permeable layers in aquifer one are shown to occur as a series of permeable, iron stained, poorly connected and laterally discontinuous lenses, within and often separated by less permeable sandy or tight claybound gravels. Lenses range from a few centimeters to 20 m wide and from a few centimeters to 1 m thick (Davey, 2006 b). Oliver (1946 a) describes aquifer one as consisting of '*lenticular layers of loose gravel, alternating with similar layers and lenses of tighter gravel, and of sand and clay'*. This mode of occurrence has been noted by well drillers and farmers for many years Davey (2006 b). Photos of dry and flowing lenticular lenses taken during this study and those taken by Davey (2006 b) are shown in Figures 2.10 and 2.11.

2.5.4 Discussion

Aquifer One

Many authors (Wilson 1973, Thorpe and Scott, 1991, Bal, 1996) have suggested that aquifers occur in more permeable re-worked interglacial sediments, separated by less permeable glacial outwash gravels referred to as aquitards. A majority of the Hinds Rangitata Plain gravel deposits

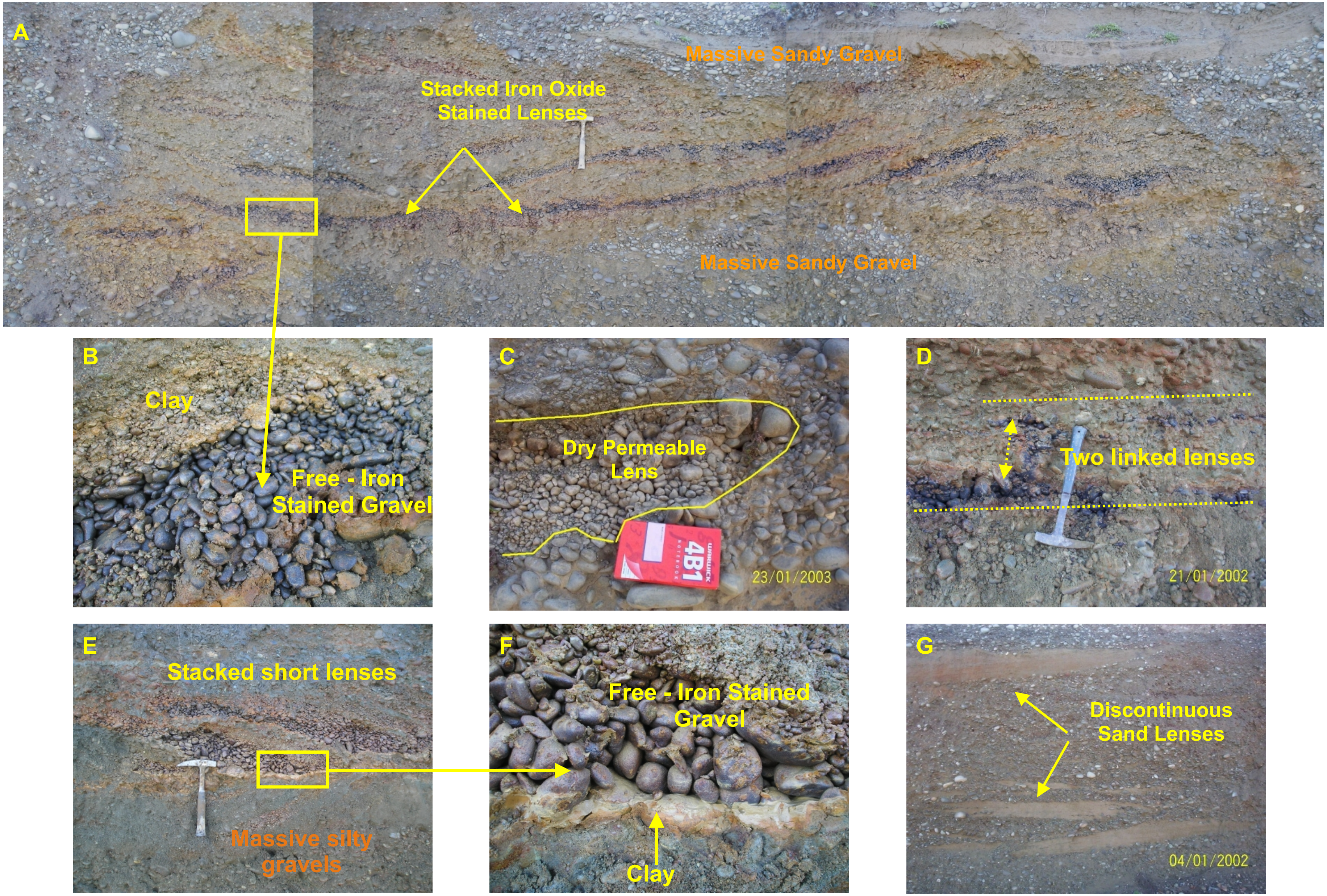

Figure 2.10 - (A) Free, iron stained gravel lenses in massive sandy gravel (Lowcliffe cliffs). (B) Free, iron stained gravels overlain by claybound gravels. (C) Dry permeable gravel lense from a pit 30km inland from the Ashburton coast (Davey, 2006 b). (D) Link between two permeable lenses (Lowcliffe cliffs) (Davey, 2006 b). (E) Short stacked permeable lenses (Lowcliffe cliffs). (F) Iron stained gravel lense underlain by clay and overlain by claybound gravels. (G) Discontinuous sand lenses (Lowcliffe cliffs) (Davey, 2006 b).

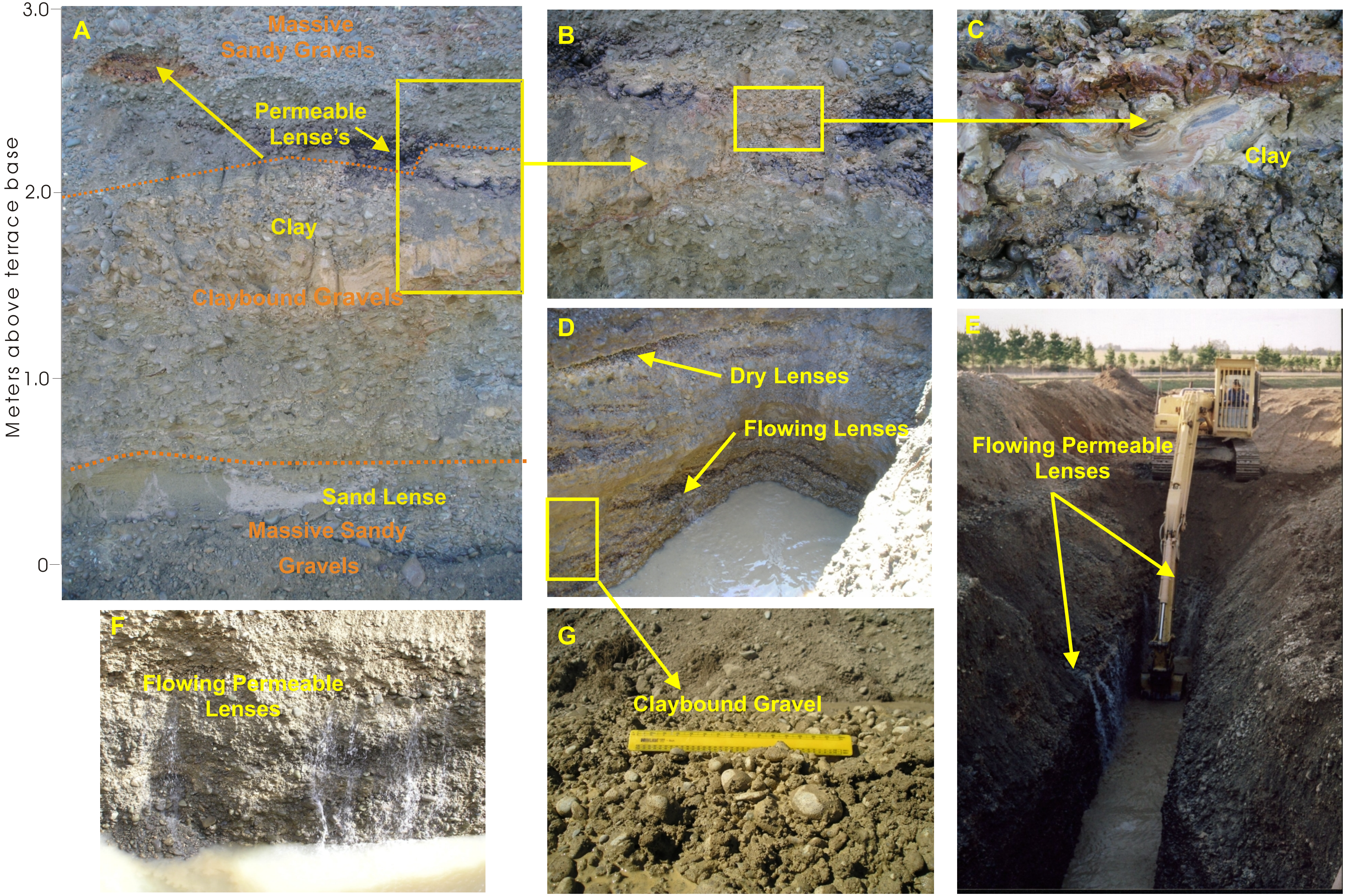

Figure 2.11 - (A) Free - iron stained gravel lenses overlying claybound and massive sandy gravels (Lowcliffe cliffs). (B) Iron stained gravel lenses separated by claybound gravels. (C) Claybound gravels. (D) Gallery (K37/2801) 10k m inland from the Lowcliffe coast, showing dry and flowing permeable lenses. (E) Gallery (K37/1646) 10 km inland from the Lowcliffe Coast, with flowing permeable lenses (Davey, 2006 b). (F) Gallery K37/1893 30 km, inland from the Ashburton coast, with flowing permeable lenses (Davey, 2006 b). (G) Hard and tight claybound gravels struck at 4 m.

exposed on the fan surface are described as glacial outwash, deposited by the Rangitata River during the Otiran glaciations. Glacial sediments are generally less sorted and contain more fine sediment. This may explain why the first aquifer is considerably claybound. If channel features were not eroded at the time of deposition or post deposition, then a large number of wide, highly interconnected permeable channels could potentially be retained at depth. However permeable layers in aquifer one occur as a series of poorly connected and laterally discontinuous lenses. These lenses likely formed from the erosion of larger remnant channels during and post-deposition, and from fine sediment being washed through the aquifer by groundwater. From outcrop observations of aquifer one (shown in Figure 2.11), groundwater flow is considerably higher in these lenses in comparison to the flow emitted from the surrounding sediment which is less permeable. Davey (2006 b) stated that the success of a gallery or well is often dependent on the number and size of the permeable lenses intersected.

The discontinuous nature of these lenses is clearly shown in Figure 2.10 and 2.11. Oliver (1946 a-c) provides three examples for the vertical separation of these permeable lenses. He reports of well drillers striking water at shallow depths, and 20 – 40 m away water not being struck until much greater depths (Oliver, 1946 c). In another example at Winslow Rd on the south bank of the Hinds River, small quantities of water were obtained to a depth of 3 m. At this depth a layer of limonite (refer to Section 2.5.5) was encountered, below which the ground was dry until the true groundwater level was struck at a greater depth (Oliver, 1946 c). This is a possible example of a perched water table (Figure 2.12). Another example of a perched water table was when a farmer reported that his well went dry, too obtain water he raised the pipe 1 m. Again this could occur if two water bearing layers (or lenses) were separated by an impervious layer such as claybound gravels or ironstone (Figure 2.12).

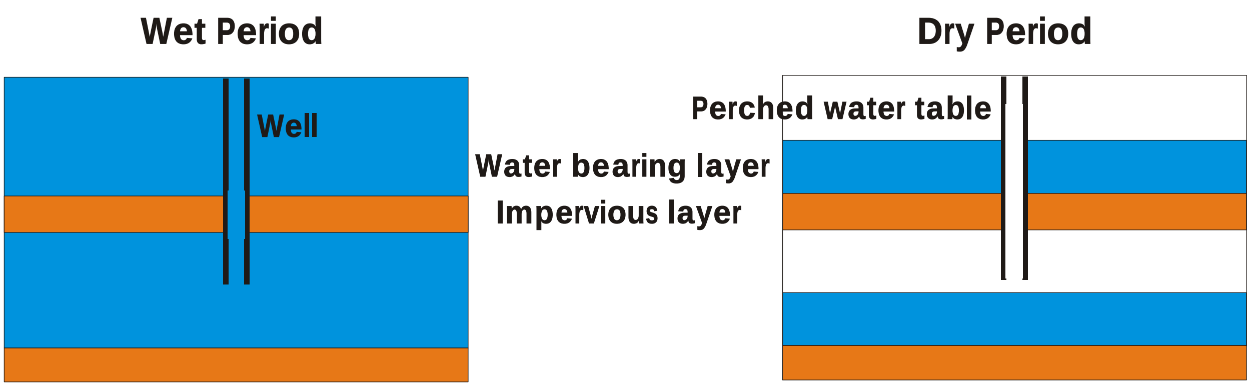

Figure 2.12 – An example of a perched water table. Potentially, water could be obtained during the dry period by lifting the well screen above the impervious confining layer.

Photos D and G in Figure 2.10 show the vertical separation between a flowing permeable lens (bottom) and a dry permeable lens with sandy and claybound gravels. Photos A – C in Figure 2.10 show horizontal separation of permeable lenses by claybound gravels. It is likely that this mode of groundwater occurrence would make it difficult to predict the pumping effects on neighboring wells and surface water bodies. Wells tapping the same permeable lenses may induce large local effects, whilst wells tapping separate lenses may have little or no effect. During the course of this study, automated water level readings from well K38/0385 (8 m deep) showed no effects from the pumping of irrigation gallery K37/2250 (10 m deep), 300 m across gradient. Thus the presence or absence of these permeable lenses also changes the nature and occurrence of groundwater laterally within the aquifer.

Aquifer One – Hinds Fan

Upstream of Surveyors Rd, the Hinds River Fan (HD1 deposits) is characterized by a narrow braided bed with the single large channels. In contrast, the fan surface downstream of Surveyors Rd (HD2 deposits) is characterized by numerous narrower, sinuous, meandering channels that are more SW orientated. Despite the modification of channels from fluvial erosion and groundwater flowing through the aquifer (discussed above), groundwater might be expected to flow quite differently within HD2 deposits compared with HD1 deposits, as a result of the different channel patterns and type of sediment transported and deposited. The sinuous, meandering section of swamp downstream of Surveyors Rd suggests a lower energy environment, reduced sediment transport capacity, greater quantities of fines deposited and potentially reduced permeability. In addition, the sinuous nature of the channels suggests that groundwater would flow less freely. If this does occur then Hinds River gravels downstream of Surveyors Rd, could also act as a barrier to groundwater flowing within the Rangitata River gravels, which have potentially greater hydraulic conductivity, thus forming two distinctly different hydrogeological and geochemistry zones. Evidence of a separate groundwater hydrologeolical and geochemistry zone within the Hinds Swamp area is provided in Chapters 4 and 8.

2.5.5 Ironstone deposits

Ironstone deposits range from hard, tight, impermeable deposits of well cemented sand or sandy conglomerates consisting of limonite (iron oxide), to sand or gravel only lightly cemented with limonite. Limonite is a red, yellow or brown colored mixture of fine-grained iron oxides, generally dominated by goethite. Limonite can be formed through the weathering of sedimentary rock minerals containing iron, by biogenic or inorganic precipitation in wetland environments, or be precipitated out by iron rich surface water or groundwater (Wikipedia, 2006). Limonite may occur as the cementing material in iron rich sandstones or as finely disseminated sediment mixed with clays and other minerals, or as a massive isolated deposit (Wikipedia, 2006). Mapping by Oliver (1946 c - Map 4) showed that most of these deposits occur along the margins of the old Hinds Swamp. Oliver (1946 c) states that ironstone deposits are extensive but patchy throughout the wetter areas of the Hinds Rangitata Plain, and have a definite and close relation to the occurrence of a high water table.

At the Railway Bridge over the Hinds River, limonite has cemented sand and gravels so highly that gelignite charges were required to drive the piles into the ground (Oliver, 1946 c). Approximately 1.5 km away near Hinds Township, a new drain feeding the Northern Drain was dug in May 2006, in order to help lower high groundwater levels. The digger driver (name not known) stated that the ground was so hard that it had to be ripped first before the drain could be dug. Photos A and G in Figure 2.13 show the fresh drain cuttings with 30 cm layer of tight sandy gravels extending from the land surface. These overly approximately 60 cm of alternating cemented (concrete like) conglomerate and cemented sand layers, interpreted to be ironstone formations. In contrast, outcropping ironstone deposits, in the bed of the Hinds River (Figure 2.13) were far more permeable and ranged from slightly cemented conglomerates to unconsolidated limonite coated sand. Yet despite the relative increase in permeability, flow in the river was highly affected by these deposits. Photo B (Figure 2.13), shows the flow in the Hinds River ending just downstream of Hinds Township. Downstream of photo B, groundwater underflow was brought to the surface at locations where ironstone was visibly outcropping in the bed of the river. Where there was no visible ironstone, the river was dry. This suggests that ironstone deposits are able to force groundwater to the surface, a mechanism which could partly account for areas with a higher water table and more abundant springs.

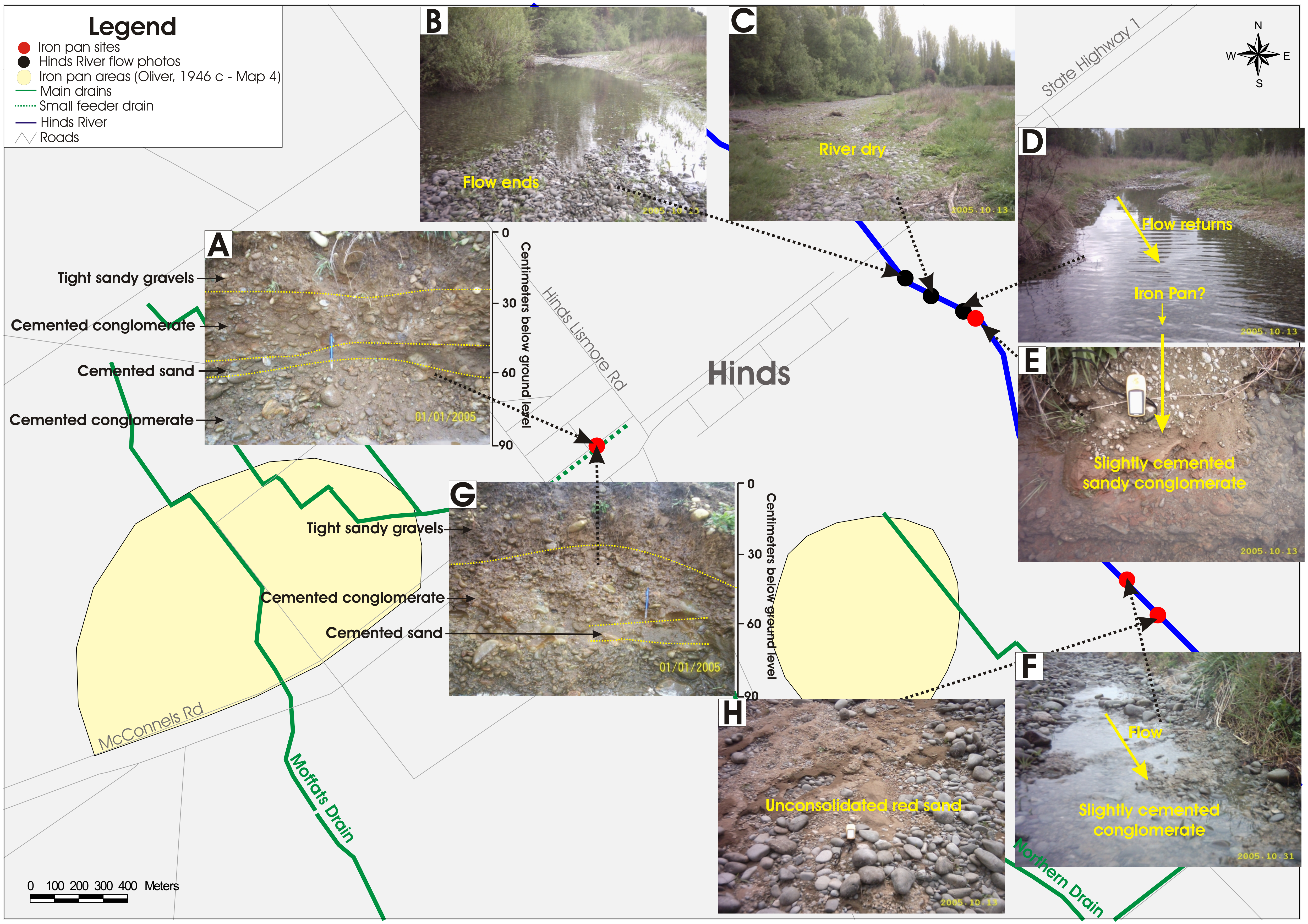

Figure 2.13 - Map showing the location of ironstone deposits mapped by Oliver (1946 c - Map 3) and those found during the course of this study in this area. The permeability of ironstone was found to be far greater in the Hinds River than that found outcropping in the drain cuttings. Photos D to F show reaches where the Hinds River started flowing, from dry. These reaches (in Photos D to F) coincided with areas of exposed ironstone.

2.6 Summary

The majority of the Hinds Rangitata Plain were formed during glacial periods within the Late Quaternary (approximately 400,000 ago to present). Gravel deposits are predominantly glacial outwash, sourced from the Rangitata River and occur to a depth of 637 m, the greatest thickness recorded on the Canterbury Plains. Ashburton River deposits are restricted to a narrow (approximately 6 – 10 km) sector of the Plains between the Rangitata River and Rakaia River Fans (Brown, 2001). The smaller unglaciated Hinds River occupied the depression between the two larger Rangitata and Ashburton River fans. During postglacial times the Hinds River originally flowed into a swamp half way between Boundary and Surveyors Rd. Bacterial processes within this swampy area are believed to have resulted in the deposition of generally impermeable limonite (ironstone) deposits. These are thought to be partly responsible for higher water table areas, the occurrence of springs, and perched water at some locations.

Gravels of the Rangitata Fan are massive or poorly stratified greywacke, consisting of clasts in a silty sand matrix. Minor quantities of volcanic rock and limestone are also present. Most of the fan surface is characterized by low relief braided river channels, similar to those occurring today in the active channels of the lower Rangitata River. From Mayfield Township to Surveyors Rd, the Hinds River Fan is slightly braided but dominated by single larger channels. Downstream of Surveyors Rd, the fan surface is characterized by numerous narrow, sinuous and meandering channels formed within a wetland environment. These gravels may be less permeable and act as a barrier to groundwater flowing through Rangitata River gravels.

A majority of the Hinds Rangitata Plain gravel deposits exposed on the fan surface are described as glacial outwash, deposited by the Rangitata River during the Otiran glaciations. Poorer sorting and more fines in glacial sediments may explain why the first aquifer is considerably claybound. Permeable layers in aquifer one occurs as a series of poorly connected and laterally discontinuous lenses. These lenses likely formed from erosion of larger remnant channels during and post-deposition, and from fine sediment being washed through the aquifer by groundwater. These permeable layers are the dominant source of groundwater from aquifer one.

Chapter Three

Hydrogeology

3.1 Introduction

This chapter identifies and characterizes the aquifer and aquitard sequences both spatially and with depth beneath the Hinds Rangitata Plain. These sequences were identified from cross-sections and Aquidef plots derived from bore log data, a comparison of peizometric heads and well depths derived from a peizometric survey in March 2006, and simultaneous water level readings and geological logging of three wells nears Hinds Township. Aquifers are described in terms of their geology, depth to groundwater, seasonal water level fluctuations, specific capacity, transmissivity and groundwater flow direction.

3.1.1 Aquifer identification

Outside the Christchurch artesian aquifer system, the geometry of the Canterbury Plains aquifers is poorly understood (Davey, 2006 a). It is generally recognized that distinct aquifers do occur but there have been few attempts to systematically define and map them in three dimension (Davey, 2006 a).

Aquifers are difficult to interpret from bore log descriptions for a variety of reasons:

- Contrasts between gravel deposits are not easily discernable from bore log descriptions and it is likely that there are only subtle differences between aquifer and aquitard sediments.
- Almost all bore log descriptions are recorded by drillers who are untrained in geological logging.
- It is difficult to describe sediments accurately from material brought to the surface by modern rotary drilling methods.
- Groundwater is likely to flow through numerous permeable remnant channels acted upon by different primary and secondary depositional process producing local variations in permeability, grain-size and sorting.

With the exception of Oliver (1946 a - d) and Davey (2006 a - b), previous work on the hydro-geology of this area is limited. Oliver (1946 a - d) provides a detailed description of the nature and occurrence of the first aquifer coastward of State-Highway 1. Brooks (1998) drew a cross section of the first aquifer parallel to State-Highway 1, from Hinds Township to the Rangitata River. Davey (2006 a) identifies three distinct aquifers, describing them in terms of their geology and hydrogeology. A 3D conceptual model of the aquifer/aquitard sequence, aquifer geology, static water levels, surface geology and fluvial system between the Hinds and Rangitata Rivers is provided (Figure 3.1). The following sections provide a detailed discussion of the hydrogeology based on this model of 3 aquifers and two potential aquitards.

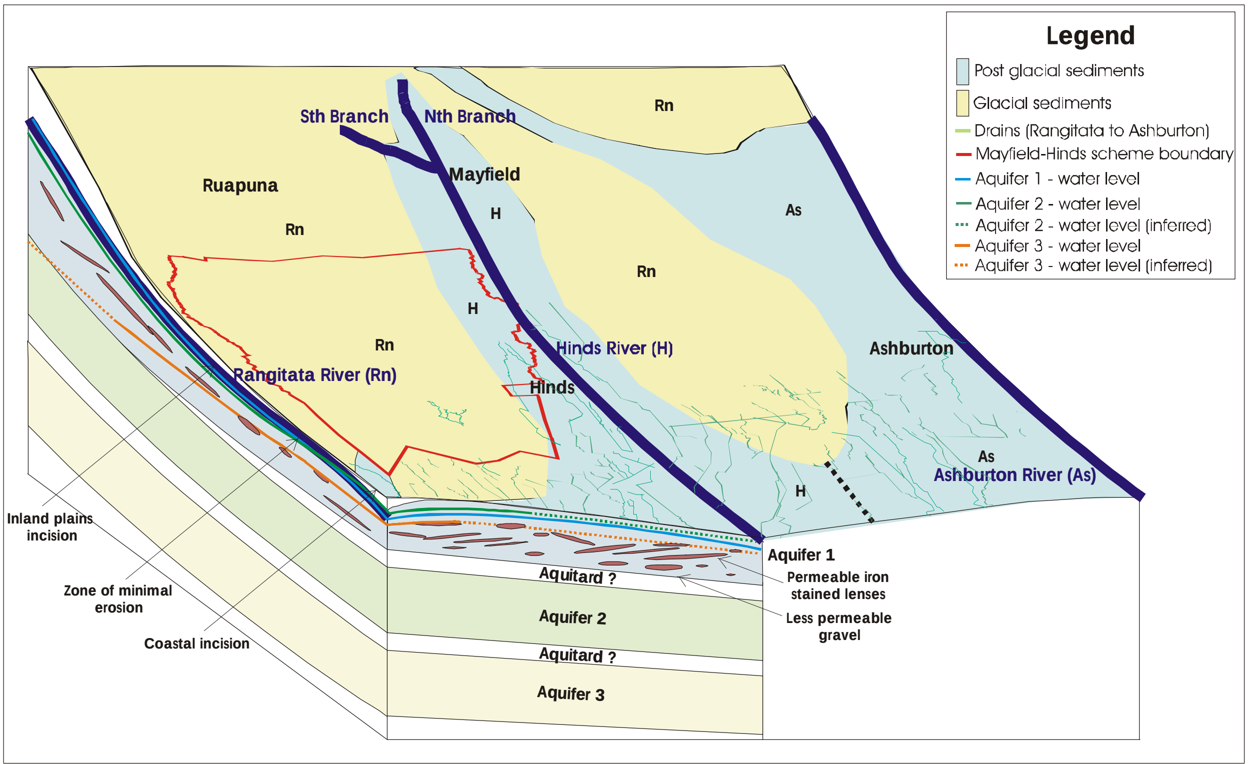

Figure 3.1 – 3D conceptual model of the hydrogeology, surface geology and fluvial system of the Hinds Rangitata Plain.

3.2 Hinds Rangitata Plain Hydrogeology

The following Hydrogeological description of the Hinds Rangitata Plain is primarily based on bore log data (using Aquidef) and water levels taken from 147 wells, during a piezometric groundwater survey in May 2006. In order to account for the spatial variability of groundwater levels, the area was broken up into 5 Hydrogeological Sections and one sub-section. The location of each section is provided in Figure 3.2 in the text, and Figure 3.2 in the back pocket.

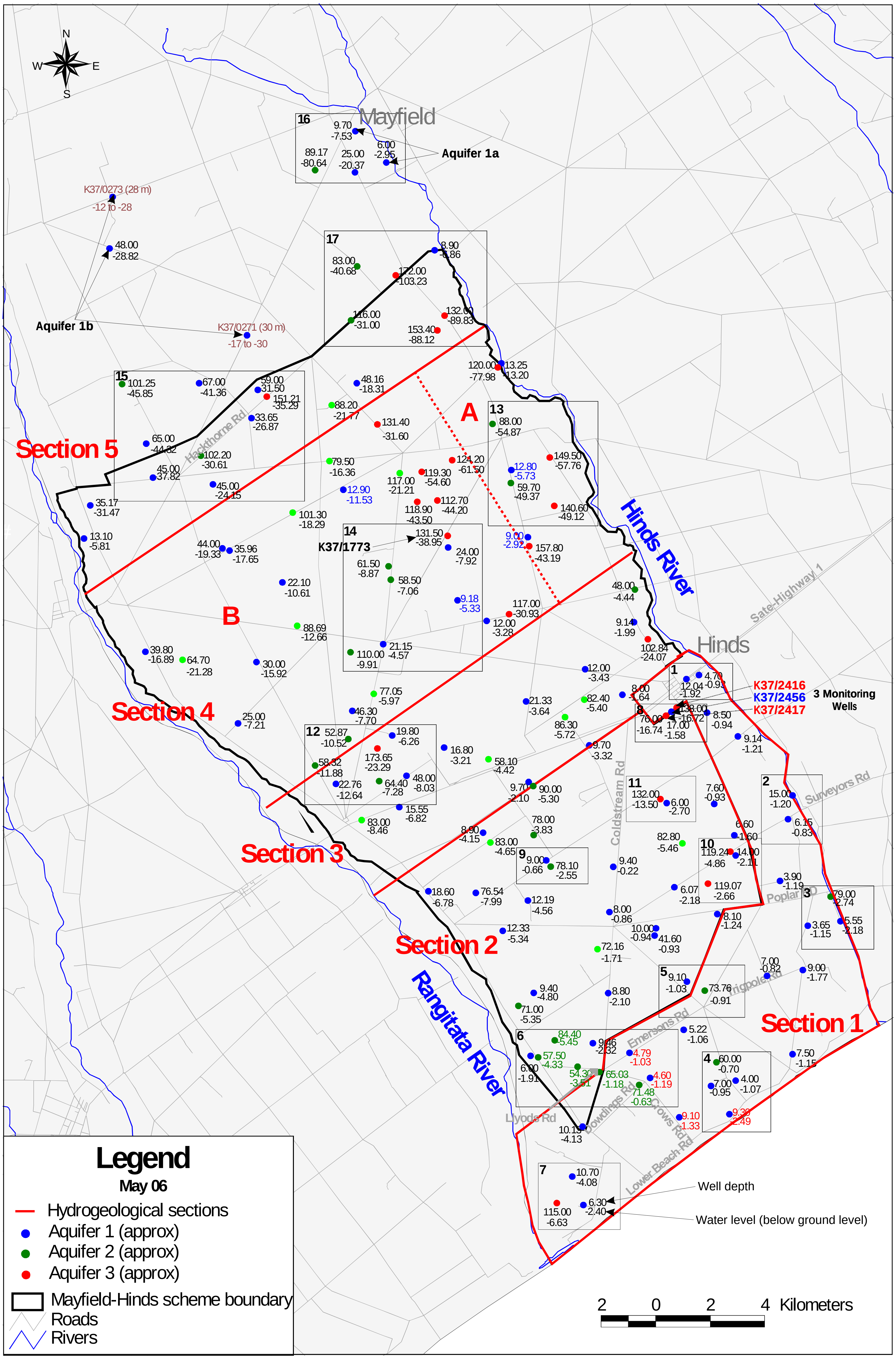

Figure 3.2 - Five Hydrogeological Sections and one sub-section were identified within the Hinds Rangitata Plain. The location of wells, well depths, water levels (at May 2006) and the inferred aquifer of each well are also provided. Boxed sections and highlighted well details are discussed in greater detail within Chapter 3.2.

3.2.1 Use of Aquidef

Aquidef (Davey, 2004) is an MS Access program that works with Environment Canterbury's wells database to define aquifers and aquitards by producing histograms of the geology (taken from bore log descriptions) and well details (e.g. depth and screen distribution) for a selected area. The program can calculate the percentage of wells containing a lithological parameter (e.g. claybound gravels) at 1 m depth intervals below the ground. For example, the histogram would show 50 percent claybound gravels from 5 to 6 meters below ground level, if from 5 and 6 meters below ground level, 50 out of 100 wells had claybound gravels recorded in their bore logs.

Poorly described or incomplete bore logs may mean that the general aquifer / aquitard sequence of an area can no not be accurately determined from a single bore-log. Cross-sections often use between 10 – 20 wells. These are a more accurate way of determining the actual geological structure, as repeat descriptions of the same materials provide more certainty in the accuracy of individual bore logs. Aquidef plots for each Hydrogeological Section, discussed in this report, use bore log data from 37 to 89 wells. Assuming that a greater percentage of the bore logs are accurate rather than in-accurate, this method of aquifer identification is useful in providing a broad description of the aquifer system for a particular area. Breaking the region into different areas helps to account for the spatial variability of the aquifer system. The following Aquidef analysis was carried out in April 2006.

Aquidef parameters most clearly showing potential aquifers and aquitards were selected for each individual hydro-geological section. These were selected after graphing many different parameters, most of which were not included in this report. A relatively high number of screens, a high percentage of free gravels and iron staining, and a low percentage of clay, claybound gravels and tight gravels, all indicate the presence of an aquifer at depth beneath the ground. The depth ranges for potential aquifers and aquitards are drawn onto each Aquidef plot.

Davey (2006 a) also carried out an Aquidef analysis of the Hinds Rangitata Plain aquifers, breaking the area up into five hydro-geological sections. Though the locations of these sections differ from those used in this study, the aquifer / aquitard sequences and depth ranges for the sequences were similar to this study.

3.2.2 Section 1

For much of section 1, groundwater response to Mayfield-Hinds Scheme recharge, rainfall recharge, and groundwater chemistry are distinctly different in comparison to section 2. Section 1 follows the general outline of the original Hinds swamp, and the boundary between the sections 1 and 2 is marked by the abundant presence of springs.

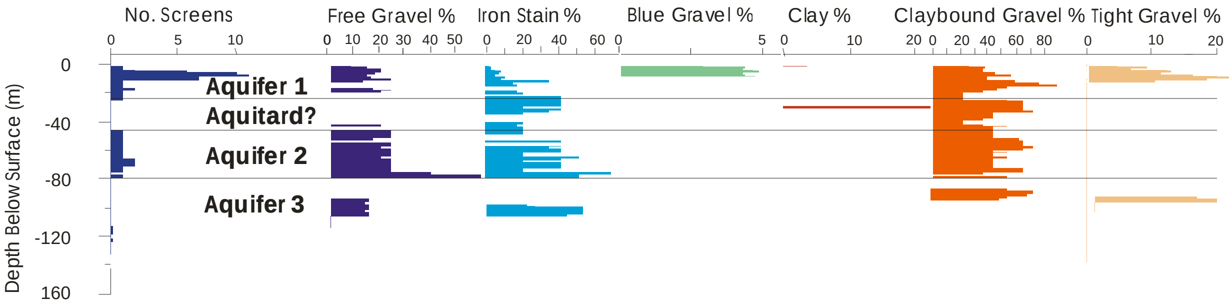

Figure 3.3 – Screen distribution, geological features and inferred aquifer/aquitard boundaries in Section 1.

Aquidef plots in Section 1 were derived from 37 wells with bore log data and 28 wells with screens. Screen distributions suggest a first aquifer from 0 – 25 m (Figure 3.3). Despite this there are very few irrigation wells (> 20 m deep) within 3 km of the coast. Individual bore logs and Aquidef plots show no evidence that the gravels are any less permeable at this depth range, than in any of the other 4 Sections. Thus the absence of shallow irrigation wells (< 20 m deep) is more likely due to the presence of drains which are used as an alternative to groundwater sourced irrigation. The blue gravel recorded in the top 2 – 3 m is generally attributed to the reduction of iron in the presence of carbonaceous material (Davey, 2004). This likely reflects the past swamp environment which covered most of this section (shown in Figure 6.1) and is evident by the common occurrence of peaty soils. From 25 – 45 m there are no screens, no free gravel, less iron staining, and a small increase in claybound gravels. This suggests the presence of an aquitard. However there could be considerable groundwater in this interval that has not been utilized because of the readily available shallow groundwater and drains (Davey, 2006 a).

Screen distribution, a reduction in claybound gravels and an increase in free gravels suggest a second aquifer from 45 to at least 80 m. It is likely that a third aquifer occurs from 80 to at least 120 m depth.

The groundwater level in aquifers one and two is generally highest in this section. In the first aquifer Oliver (1946 c) believes the high water table is caused by a reduction in permeability due to the increased presence of limonite and possibly claybound gravels. Oliver (1946 d) also noted how the water level in aquifer one (along Crows Rd) drops down to sea level at the foot of the sea cliffs. The wells highlighted in red (Figure 3.2) show the drop in water table from Emersons Rd to Lower Beach Rd in a rough line running parallel to Crows Rd. Areas where the water table drops away from a river suggest flow losses from the river and vice versa. First aquifer wells close to the Hinds River suggest that the Hinds loses flow to groundwater near Hinds Township (Figure 3.2 – Block 1), and gains flow from groundwater downstream of Surveyors Rd (Figure 3.2 – Blocks 2 - 3). This backs up evidence of the flow losses and gains from the Hinds River, provided in Chapter 6.5.

Approximately coastward of Emersons Rd, water levels in aquifer two are higher than aquifer one (Figure 3.2 – Blocks 4 - 6). This suggests an upward hydraulic gradient with groundwater flow from aquifer two into aquifer one. This upward hydraulic gradient at the coast also occurs between the Hinds and Ashburton Rivers, however summer groundwater abstraction from aquifer 2 lowers the pressure in this aquifer and the hydraulic gradient can reverse, possibly lowering water levels in the first aquifer (Davey, 2006 c). This change in hydraulic gradient may also occur between the Hinds and Rangitata Rivers. There are currently 15 second aquifer irrigation wells east of State Highway 1 and 16 proposed. West of State Highway 1, there are 20 second aquifer irrigation wells and 13 more proposed. Future increases in groundwater abstraction from aquifer 2 may cause reversals in the hydraulic gradient, if this is not already occurring. Inland from approximately Poplar Rd, the depth to groundwater in aquifer two is greater than in aquifer one (Figure 3.2 - Block 3), suggesting a downward hydraulic gradient with flow from aquifer one down into aquifer two. In contrast, the water level in aquifer 3, 1.5 km inland from the coast is approximately 3 – 4 m lower than aquifer 1 (Figure 3.2 – Block 7).

3.2.3 Section 2

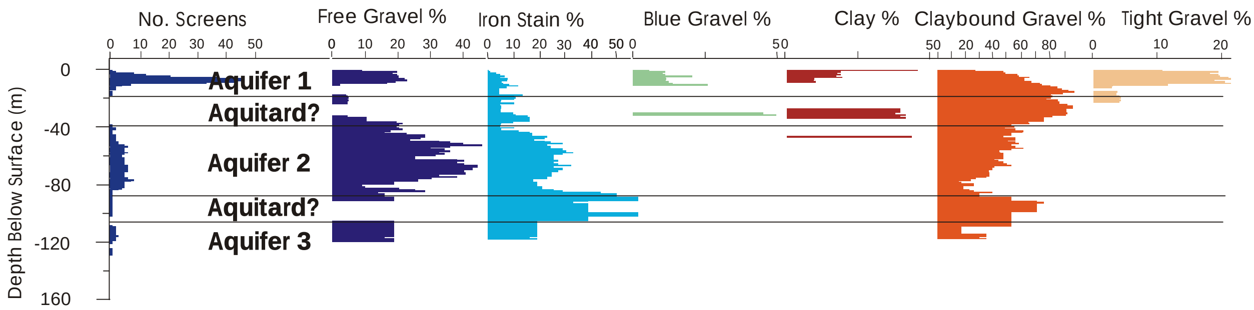

Figure 3.4 - Screen distribution, geological features and inferred aquifer/aquitard boundaries in Section 2.

Aquidef plots in Section 2 were derived from 89 wells with bore log data and 75 wells with screens. Screen distribution suggests a first aquifer from 0 – 20 m (Figure 3.4). Gravels are highly claybound and the claybound percentage increases from 0 m (40 %) to 20 m (90%) depth. Like section 1, blue gravels are also recorded in the top 2 – 3 m suggesting that parts of the area were once wetlands. These wetter areas likely occurred north east of Coldstream Rd where the water table is higher and springs are most abundant (shown in Figure 6.1). From 20 – 40 m there are no screens, virtually no free gravel, and an increase in clay. However drill logs of K37/2146 (Appendix 3.1) show aquifer one occurring down to 40 m, though with an absence of wells between 20 and 40 m, it is unknown whether sufficient yields of water occur within this depth range.

Screen distribution, proportion of claybound gravels, increased free gravels and iron staining suggest that aquifer two exists from 40 to 90 m. Water levels in aquifer two are consistently 2 - 3 m lower than aquifer one (Figure 3.2 – Block 9). The five second aquifer wells highlighted in green (Figure 3.2 - Block 6) show how water levels drop towards the Rangitata River and with increasing distance inland from the coast. Wells parallel with Llyods and Crows Rd show how the water level in aquifer two dropping to below that of aquifer one, and a subsequent shift to a downward hydraulic gradient (flow from aquifer one to aquifer two) within 1 km.

From 90 – 105 m claybound gravels increase, whilst free gravels decrease, suggesting a relatively confining layer. Screen distribution, less claybound gravels and an increase in free gravels suggests a third aquifer between from 105 m to at least 135 m. Block 10 (Figure 3.2) shows a (possible) third aquifer water level between -2.7 and – 4.9 m. Blocks 11 and 8 show a third aquifer water level of -13.5 and -16.7 m respectively, suggesting a significant drop in water levels with increasing distance inland. In contrast, the water level in aquifers one and two also drop inland but at a lesser rate.

Aquifers near Hinds Township

The three aquifers described in Section 2 are proven by strata logs and water level measurements taken during the drilling of three wells near Hinds Township (shown in Figure 3.2 – Block 8). A description and interpretation of the lithology (from bore logs provided Appendix 3.1) and water levels (Figure 3.5) taken during the drilling of K37/2416 (138 m deep) are provided below.

- Aquifer One – Between 0 and 40 m, gravels were sandy and claybound (clay becoming less from 20 m), and water levels taken at successively deeper depths ranged from -1.4 to -1.9 m below ground level.

- Aquifer Two – At 47 m depth the water level dropped to -4.6 m. Water levels were approximately 2 - 3 m lower than aquifer one, and varied between -3.6 and -5.5 m between 47 m and 72 m depth. Gravels between these depths were generally described as sandy and silty, clay was noticeably absent or present in only minor quantities.

- Aquifer Three – At 89 m depth the water level dropped to -15.4 m below ground level. The water level varied between -15.1 and -22.6 m between 89 m and 126 m depth. Note that well K37/2417 (76 m deep) was drilled less than 100 m from well K37/2416, and shares the same deep water levels as K37/2416. Gravels between these depths were generally described as sandy and silty with the exception of a thick claybound unit (potential aquitard) between 106 and 120 m.

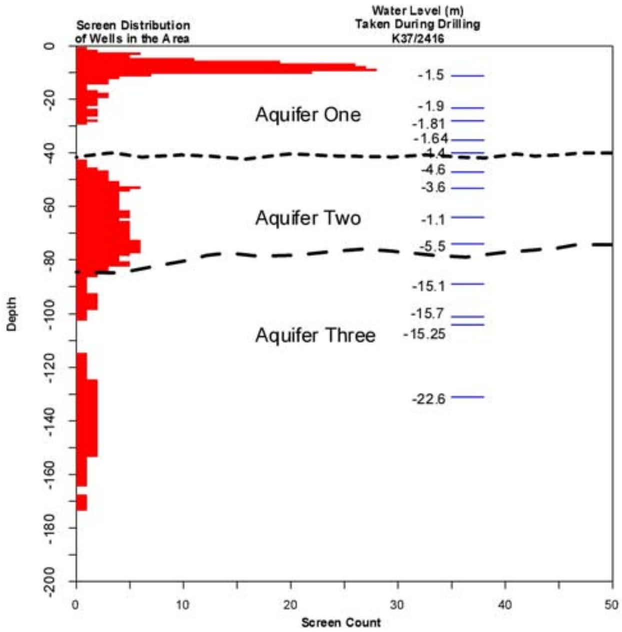

Figure 3.5 – Screen distribution and water levels taken during the drilling of well K37/2416 (138 m deep) near Hinds Township (source: Davey 2006 a).

Near Hinds Township, aquifer one occurs within a relatively impermeable layer from 0 – 40 m depth. High yielding wells drilled into this aquifer are likely taping permeable lenses within this highly claybound layer. Aquifer 2 occurs within a more permeable gravel unit (very little clay) from approximately 40 to 76 m. Water levels from other second aquifer wells in this section suggest that aquifer two extends down to 90 m. A confining layer between aquifers two and three was not identifiable through the bore log descriptions. Though a less permeable unit was logged between 106 and 120 m, the sudden drop in water levels showing penetration into the third aquifer occurred above this depth. Thus this less permeable layer did no delineate the boundary between aquifers two and three. No confining layers were identified between the aquifers during the drilling of well K37/2416. As such, no confining layers have been drawn onto Figure 3.5, and only the interpreted depth ranges (below ground level) for each of the three aquifers is shown.

3.2.4 Section 3

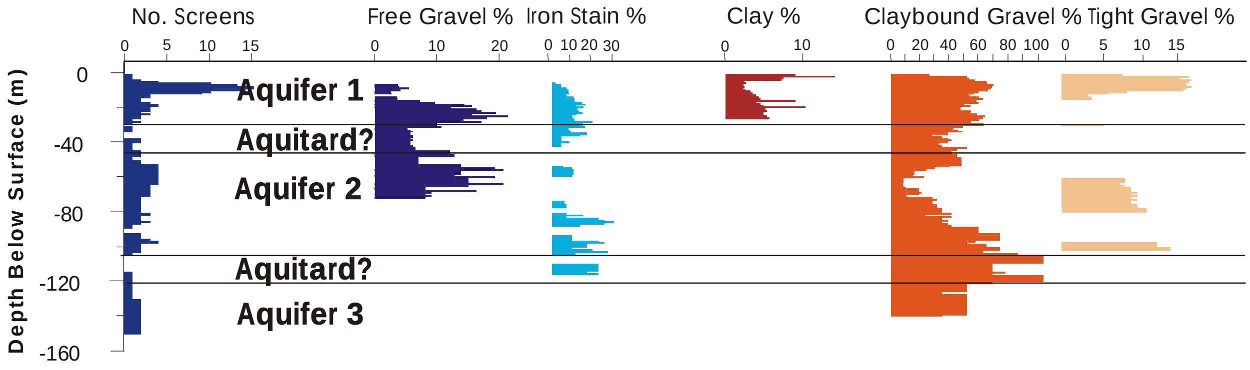

Figure 3.6 - Screen distribution, geological features and inferred aquifer/aquitard boundaries in Section 3.

Aquidef plots in Section 3 were derived from 43 wells with bore log data and 40 wells with screens. Compared with Section 2, the same three aquifers in Section 3 occur at 5 – 10 m deeper depth intervals below ground level (Figure 3.6). Screen distribution and a larger percentage of free gravels suggest that aquifer one occurs from 0 – 30 m (though it likely occurs down to 45 m). Based on Figure 3.6, aquifer two occurs within a layer of less claybound gravels from approximately 45 – 100 m. Between 100 and 120 m, gravels are highly claybound and screens are nearly absent suggesting a possible aquitard. However as noted with the drilling of K37/2416, this less permeable layer may not define the boundary between aquifers two and three. Thus from limited data, aquifer three most likely occurs from 120 – 175 m. Compared with Section 2, the water level in all three aquifers is 2 – 10 m deeper, and in general, the second aquifer water level is 1 – 3 m lower than in aquifer one (Figure 3.2 – Block 12).

3.2.5 Sections 4A and 4B

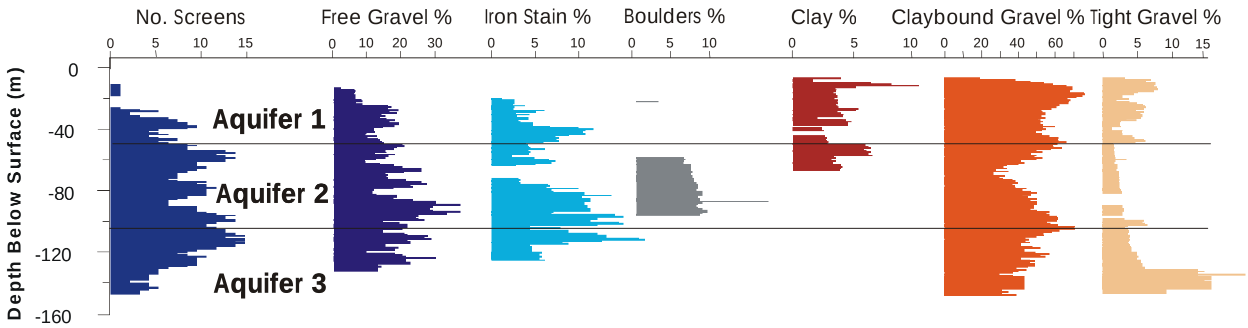

Figure 3.7 - Screen distribution, geological features and inferred aquifer/aquitard boundaries for Sections 4A and 4B.

The combined Aquidef plots for Sections 4A and 4B were derived from 87 wells with bore log data and 70 wells with screens. An increase in screen distribution, free gravels and a small reduction in claybound gravels suggests a first aquifer between 20 and 45 m (Figure 3.7). However piezometric survey data show that shallow wells (highlighted in blue, Figure 3.2) less than 10 m deep are present within 6 km SW of the Hinds River. Closer to the Rangitata River, aquifer one water levels deepen and wells are more commonly 20 – 40 m deep. Thus over this entire section, aquifer one is interpreted to occur from 5 m to at least 45 m deep.

Close to the Hinds River in Area 4A, the water level in aquifer two is deeper (and similar to aquifer 3) compared to the second aquifer water level in Area 4B which is similar to aquifer one. In Area 4A, the water level in a 13 m first aquifer well, and 60 m second aquifer well (450 m apart), were -5.7 m and -49.4 m respectively (Figure 3.2 – Block 13). Yet closer to the Rangitata River in Area 4B, second aquifer wells between 50 and 70 m depth had water levels ranging from -7.1 to -10.5 m (Figure 3.2 – Block 14). The exact cause of the lower second aquifer water levels in Area 4A could not be determined. However, the noticeable difference in the screen distribution and claybound gravel percentage between both areas (Figure 3.8) was an absence of claybound gravels in Area 4A between 105 and 160 m depth.

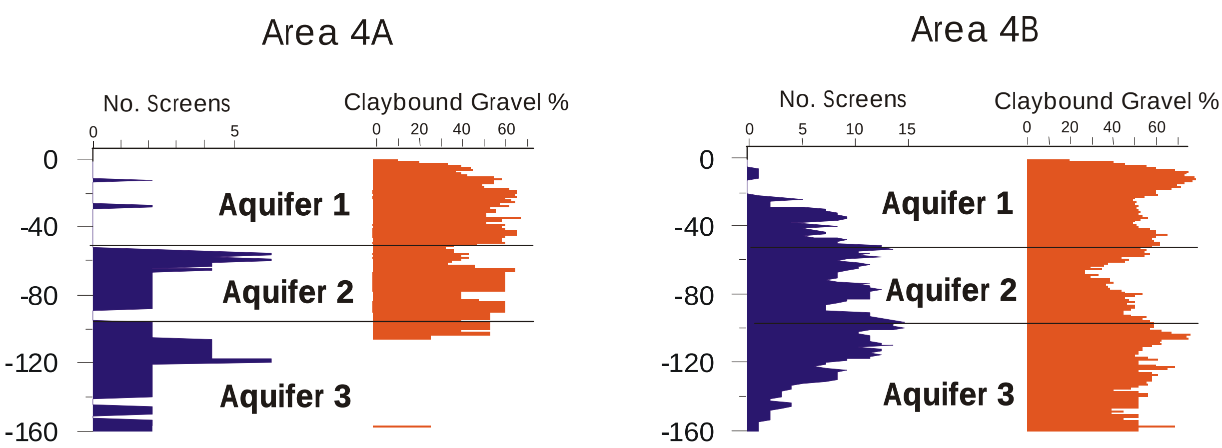

Figure 3.8 - Screen distribution, claybound gravel percentage and inferred aquifer/aquitard boundaries, for each sub-Section.

Another noticeable feature of the second aquifer is the presence of boulders between 60 and 100 m depth (Figure 3.7). Boulder sizes are difficult to determine from drilling, however many boulders may occur between 1 – 2 m wide, as boulders of these size are commonly found on the surface of RG5 and RG4 gravel deposits (Barrell et al , 1996) (Figure 2.3). From State Highway 1 to Hackthorne Rd (Figure 3.2), many farmers talk about boulders being encountered from 40 – 100 m depth. In some instances these boulders make it either difficult or impossible to continue drilling. The potential origin of these boulders is discussed by Barrell et al (1996) who found a layer of boulders up to 50 m thick beneath RG4 gravel deposits near Klondyke. These boulders are interpreted as either a lag deposit from the degradation of RG5 or as an aggradation deposit laid down during the formation of RG4 gravels.

In aquifer three, the depth to groundwater is distinctly deeper in Area 4A (Figure 3.2 – Block 13) compared to Area 4B (Figure 3.2 – Block 14). In addition, the second and third aquifer water levels in Area 4A are very similar. This makes it difficult to determine the top and bottom of aquifers two and three. Because third aquifer water levels are higher in Area 4B, groundwater is likely to flow towards the Hinds River. In summary, aquifer three extends from approximately 100 to 170 m in both Areas 4A and 4B.

3.2.6 Section 5

An interpretation of the aquifer boundaries was most difficult in Section 5. At some locations water levels were too similar to accurately distinguish aquifers (Figure 3.2 – Block 15). Water level data combined with an accurate bore-log description during drilling are required to better define the aquifers in this section.

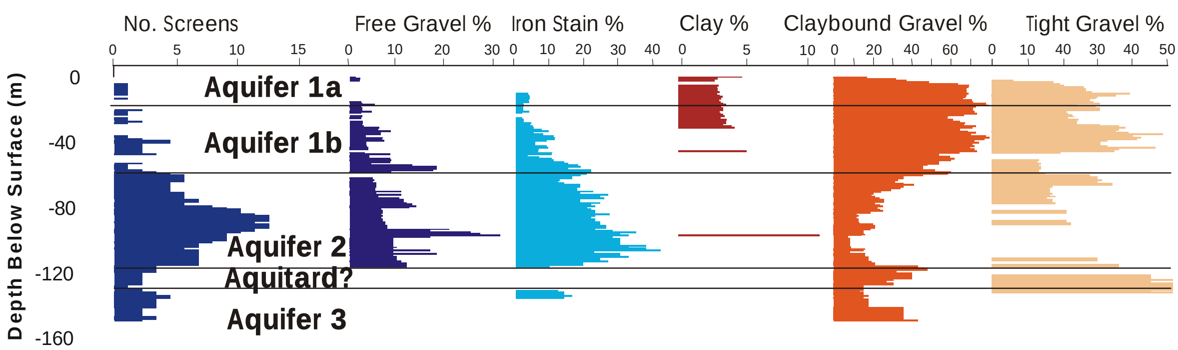

Figure 3.9 - Screen distribution, geological features and inferred aquifer/aquitard boundaries in Section 5.

Aquidef plots in Section 5 were derived from 52 wells with bore log data and 39 wells with screens. Aquidef plots suggest a first aquifer occurring within highly claybound gravels from 0 – 50 m depth. Within 500 m of the Hinds River, wells penetrating aquifer one (Aquifer 1a), are commonly between 5 and 15 m deep (Figure 3.9 and Figure 3.2 – Block 16). The existence of this shallow first aquifer is probably due to groundwater losses from the Hinds River. Water levels are highest close to the river and drop within increasing distance away from the river, suggesting losses to groundwater (Figure 3.2 – Block 16). Flow losses to groundwater from this section of the Hinds River are described in Chapter 4.4.2. 1.5 km away from the Hinds River to 5 km north of the Rangitata River, aquifer one (Aquifer 1b) is deeper and the shallowest wells occur between 28 and 30 m. Wells K37/0273 (28 m deep) and K37/0271 (30 m deep) highlighted in brown (Figure 3.2) have experienced water levels as high as 12 and 17 m below ground level respectively and all have gone dry, suggesting a larger seasonal variation in water levels compared with wells closer to the Hinds River.

A reduction in claybound gravels, tight gravels and increased iron staining suggests a second aquifer from 50 to 115 m (the permeability possibly increases with depth). No obvious aquitard between aquifers one and two could be seen from the Aquidef plots in Figure 3.9.

The existence of an aquitard between 115 and 130 m depth is suggested by the increase in claybound gravels and reduction in well screens. An increase in screen counts below 130 m strongly suggests a third aquifer below this depth, and extending to approximately 170 m. Third aquifer wells close to the Hinds River, have water levels between 88 and 103 m below ground level. (Figure 3.2 – Block 17). In contrast a 151 m (screened from 84 m) deep well (Figure 3.2 – Block 15) further away from the Hinds River had a static water level of 35 m below ground level. This tentatively suggests that the third aquifer water levels deepen towards the Hinds River. The deeper water levels further from the center of the Hinds Rangitata Plain may be caused by a mounding of groundwater derived from Mayfield-Hinds Scheme during the summer. The mounding effect would reduce with progressive distance away from the center of the Plain. However, insufficient numbers of third aquifer wells were monitored in this study to prove whether this occurs.

3.3 Hydrogeological Cross-Sections

3.3.1 Methodology

Hydrogeological cross-sections (3 km wide) were drawn to help define the aquifers. The location of the each cross section is shown in Figure 3.10. Bore-log descriptions were divided into three gravel types (1) Free gravel, which most likely represent aquifer lithologies (2) Gravel and sand (or a combination of the two), which may indicate less permeable water bearing layers (3) Clay, claybound gravel, and silty gravel which may indicate non-aquifer lithologies. Other indicators of an aquifer including screens and descriptions of water bearing, moist and iron oxide staining are also shown. Water levels taken during the piezometric survey in May 2006 were used to draw the static water levels in each aquifer. Thus the discussion comparing water levels in each aquifer is only a snap-shot in time. The high and low level for aquifer one was taken from wells with the longest water level records. There were no long-term water level records from aquifers two and three, and as such no high and low water levels could be drawn. The tops and bottoms of aquifers and potential aquitards were determined from cross-section, water level and Aquidef data.

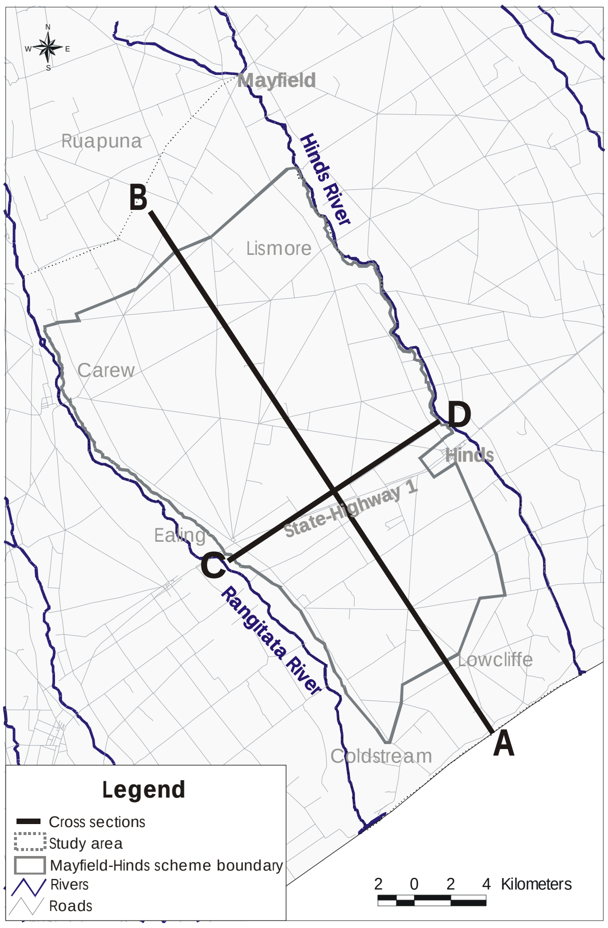

Figure 3.10 – Map showing the location of cross-sections.

3.3.2 Cross-section A – B

Cross-section A – B (Figure 3.11) extends 37 km inland from the coast, and is located half way between the Hinds and Rangitata Rivers (Figure 3.10). Three (possibly four) aquifers and two possible aquitards were identified. Aquifer one occurs from near surface to approximately 40 – 50 m, however coastward of State Highway 1, virtually no wells occur from 20 – 40 m. This suggests an aquitard from 20 to 40 m, however with an absence of wells at this depth, it is unknown whether sufficient yields of water occur within this depth range. Inland of State-Highway 1, many wells (mainly domestic supply) occur from 20 – 40 m. In addition, the sediment within this depth range is no less permeable than from 0 – 20 m. This suggests that a possible aquitard east of State-Highway 1, does not exist further inland. As no confining layer was identified in the cross-section, no confining layer was drawn between aquifers one and two, inland of State-Highway 1. From approximately 24 km inland from the coast, the groundwater level in aquifer one does not intercept the land surface. This is evident by the absence of springs and wells less than 20 m deep. The only exceptions occur near the Hinds River and on the lower terraces adjacent to the Rangitata River.

Aquifer two extends from approximately 40 to 90 m and a less permeable claybound gravel layer occurs from 90 to 120 m. Aquifer three occurs anywhere from 100 to 150 m, depending on the location, and the thickness of the overlying sediments which are generally less permeable. A fourth aquifer may occur below 150 m depth; however there are insufficient wells below this depth to prove its existence.

The groundwater water level in all three aquifers deepens with increasing distance from the coast. Within 5 km of the coast, aquifer two has a higher water level than aquifer one. Further inland, aquifer two maintains an approximately 1 to 5 m lower water level compared with aquifer one. The only exception is an area close to the Hinds River (Hydrogeological Section 4A) where water levels in aquifer two were approximately 40 m lower than aquifer one. In contrast, aquifer three water levels deepen inland at a much faster rate, suggesting a lower hydraulic gradient.

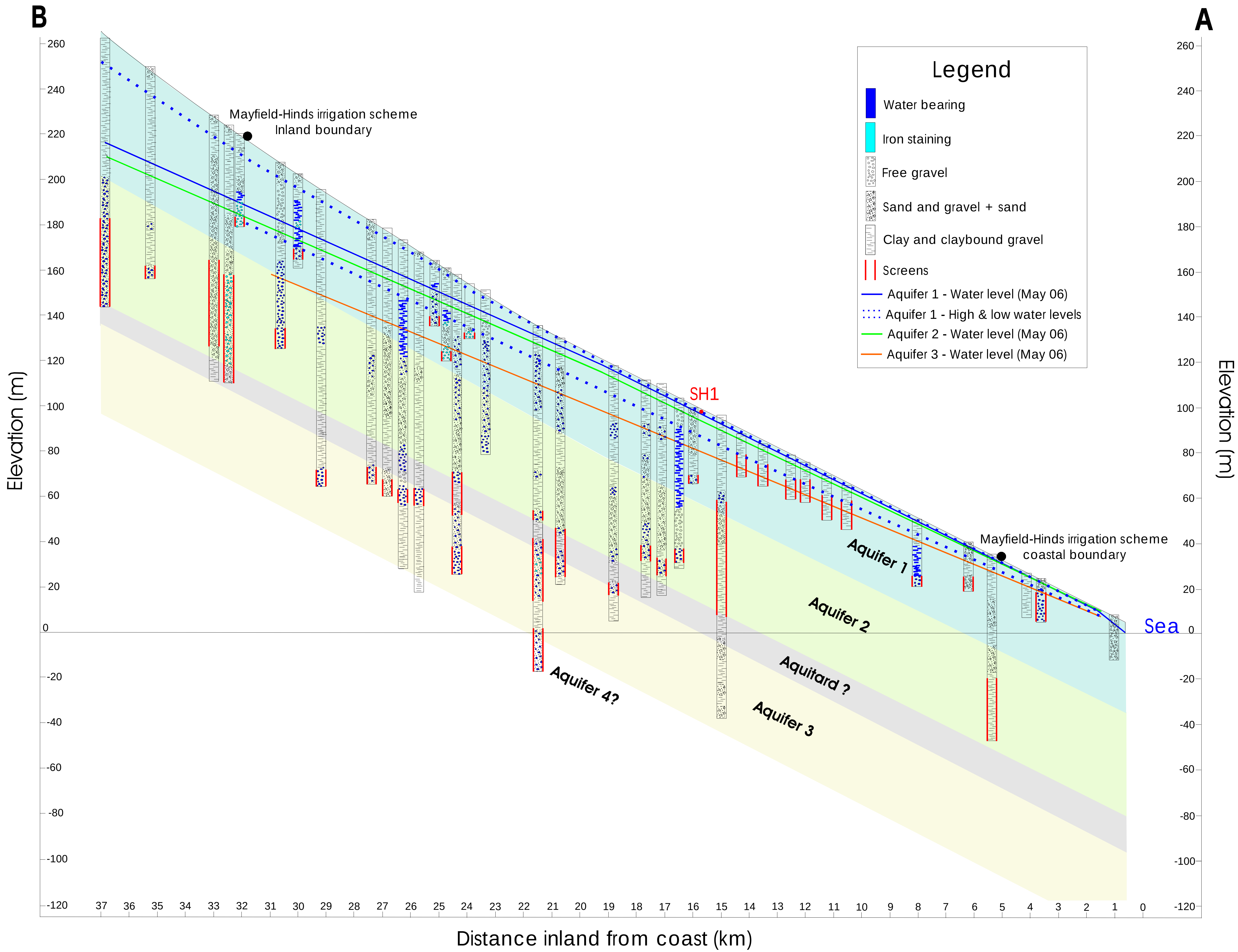

Figure 3.11 - Cross-section A - B approximately parallel to groundwater flow.

Table 3.1 – Changes in the mean static water level of aquifers one, two and three from 32 km inland of the coast. The table excludes Hydrogeological Section 4A.

	Mean Water level (m below ground level)	
	Coast	32 km inland
Aquifer 1	-1	-35
Aquifer 2	-0.75	-45
Aquifer 3	-6.5	-100

Long term water level records from aquifer one show that the seasonal variations in groundwater levels increase with increasing distance inland from the coast. Aquifer one water levels range from 0 - 2 m below ground level within 3 km of the coast water, from (at least) 2 – 12 m at approximately State Highway 1, and (at least) 19 to 42 m at Hackthorne Rd (33 km inland). Further inland near Mayfield Township, well K37/0109 (68 m deep) had a recorded highest water level of 35 m below ground level (Dec 1975). In May 2005 this well was dry, showing that the water level in aquifer two varies by at least 33 m at this location. In contrast the existence of shallow wells close to the Hinds River, upstream of Hackthorne Rd suggests that losses to groundwater from the Hinds River reduce the seasonal variation in groundwater levels despite being further inland. Surface water losses to groundwater in other areas close to the Hinds and Rangitata Rivers may also create more constant water levels.

3.3.3 Cross-section C – D

Cross-section C – D (Figure 3.12) extends 13 km perpendicular to the Hinds and Rangitata Rivers, and is located parallel to State-Highway 1 (Figure 3.10). At this location the Rangitata River is incised approximately 15 m into the Rangitata Fan. From the top of the Rangitata Fan Terrace to 10 km from NE of the terrace, the Rangitata fan drops approximately 8 m (also refer to Appendix 2.2 a). From the Hinds River 5 km SE of the river, the topographic contours show no overall change in elevation (also refer to Appendix 2.2 a). It is within this area that a large number of springs are present. The flatter gradient in this area could be due to the build up of Hinds River sourced surface gravels within the depression between the Rangitata and Ashburton Rivers.

Screen distribution and bore logs show the presence of three aquifers and two potential aquitards. Within the potential aquitard from 20 – 40 m, water bearing, iron staining, screens and layers of

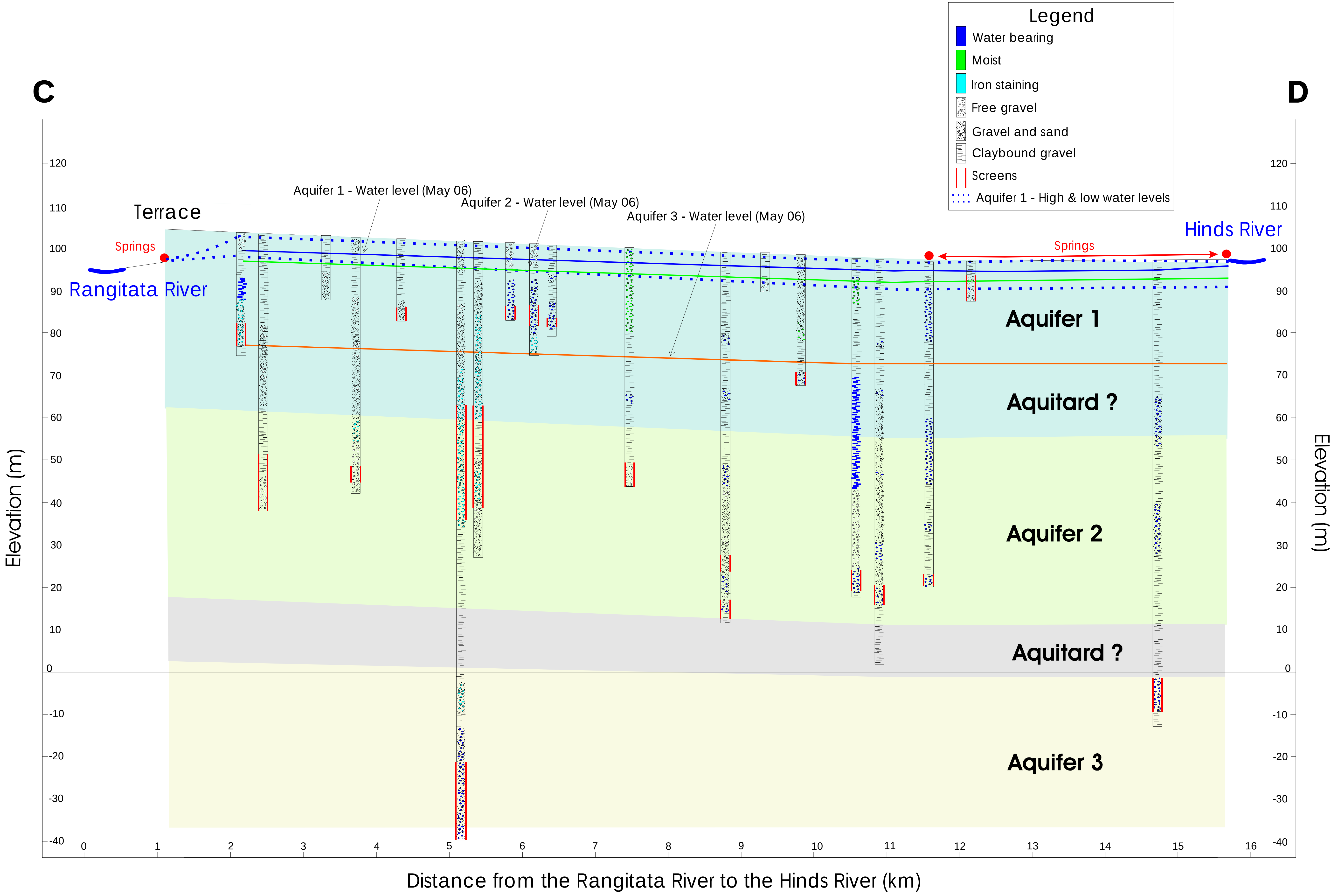

Figure 3.12 - Crossection C-D approximately perpendicular to groundwater flow.

sandy or free gravels are common, suggesting a high degree of connection with aquifer two. Depth to groundwater in aquifers one and two both deepen towards the Rangitata River and water level suggest that aquifer three may do this also. The deepening water level may be caused by the Rangitata Fan increasing in elevation towards the Rangitata River, whilst the water levels in the aquifers remain at a more constant elevation. The notable exception is close to the Hinds River. Here the water level in aquifer one 500 m out from the Hinds River was approximately 1 m higher than it was 1 km out from the River, suggesting that the Hinds River loses water in this region. Near the Rangitata River the water table slopes in towards the incised river, suggesting that groundwater in aquifer one flows into the river. The point where the water table intersects the base of the terrace is marked by the presence of springs. Springs emanating from the Rangitata Terrace, occur consistently as far inland as Ruapuna (parallel with), all the way to the coast (shown in Figure 6.1). These terrace riser springs feed drains which flow into the Rangitata River; the only exception is Oakdale Drain which generally seeps through a gravel barrier bar into the ocean. The cross-section also shows how a higher water table would result in potentially greater spring flows from the Rangitata terrace. Evidence of this also comes from local farmers who describe the springs near Boundary Rd coming up each irrigation season with the recharge from the Mayfield-Hinds Irrigation Scheme. These observations and data are also backed up by piezometric groundwater flow contours and gaugings of Oakdale which showed a doubling in flow as the groundwater table rose over the 2005/06 irrigation season.

3.4 Depth to Groundwater

3.4.1 Hinds Rangitata Plain

Water level data collected between the 8th and 9th of May 2006 was used to contour the depth to groundwater in aquifers one and two (Figures 3.13 and 3.14). It is important to note that at this time, groundwater levels in some areas had been significantly increased by recharge from the Mayfield-Hinds Irrigation Scheme. During the course of this study, depth to groundwater contours for aquifer one changed significantly. Insufficient water level data was available to show the changes in aquifers two and three. For a discussion of these changes in aquifer one, refer to Chapter 4.9.2.

Both aquifers one and two show a distinct increase in the depth to groundwater both inland and closer to the Rangitata River. Note the deeper depth to groundwater in the separate second

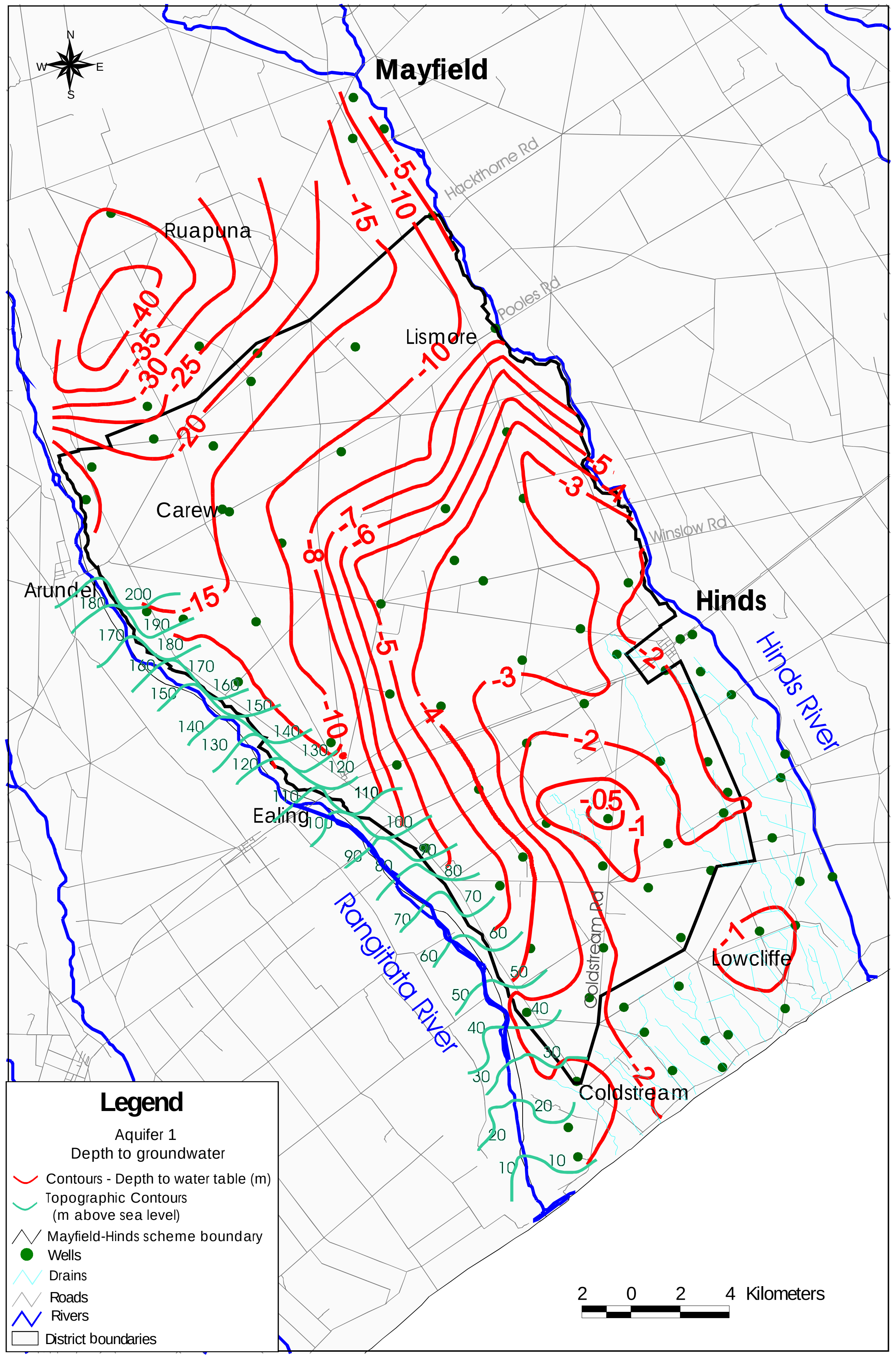

Figure 3.13 - Depth to groundwater contours for aquifer one. Topographic contours show incision of the Rangitata River into its fan, and the drains indicate the high water table areas.

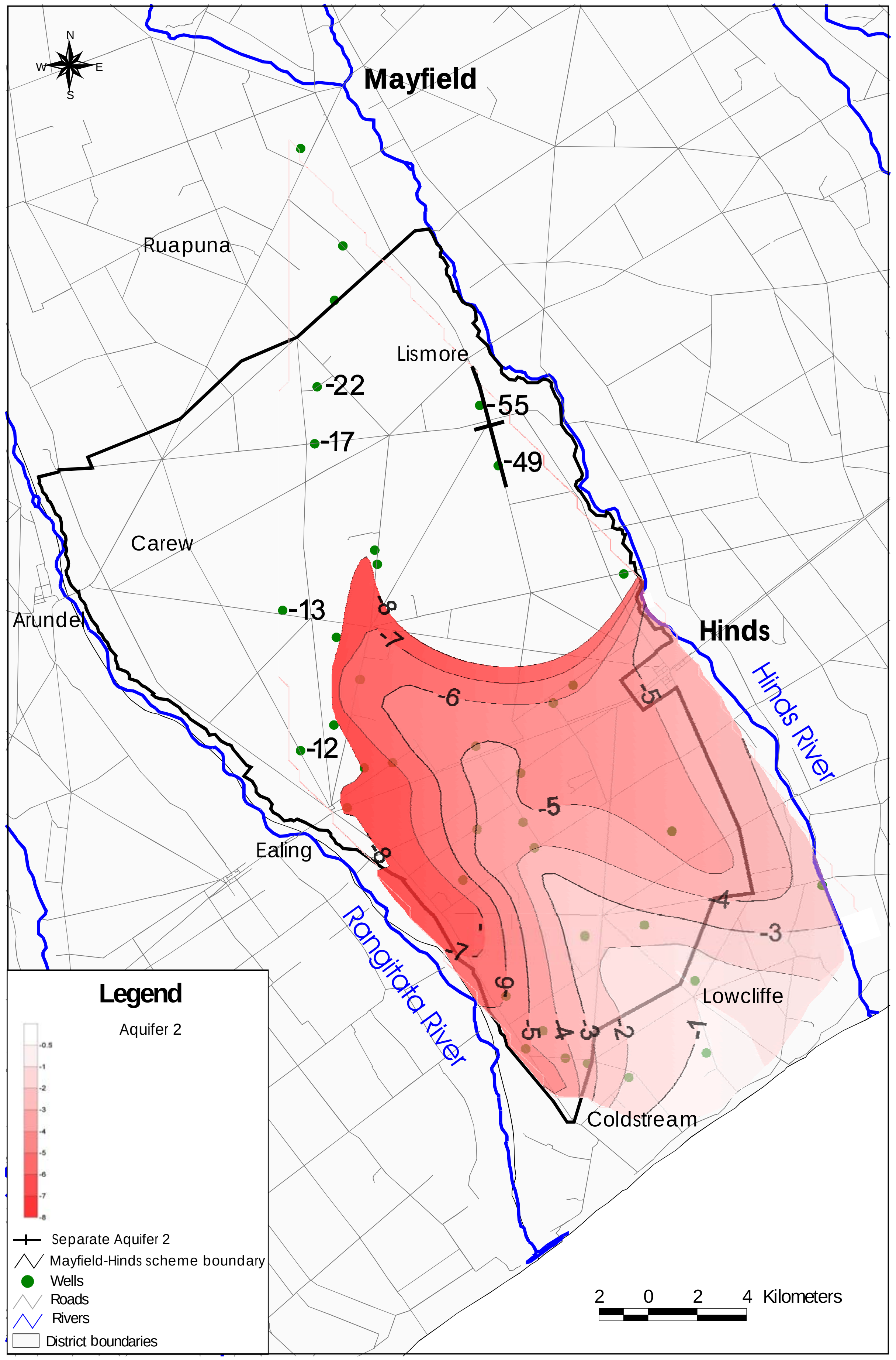

Figure 3.14 - Depth to groundwater contours for aquifer two. The cross pattern near Lismore shows the known location of the separate second aquifer where water levels are deeper.

aquifer close to the Hinds River near Lismore. More wells are required to better asses the extent of this separate aquifer. Groundwater levels are highest near the coast within the old Hinds Swamp area. Note the presence of drains in this high water table area.

3.4.2 Hinds River

From the coast inland to approximately Winslow Rd, the water table adjacent to the Hinds River remained approximately 1.5 to 2 m below ground level. Upstream of Winslow Rd to approximately 2 km upstream of Pooles Rd, the groundwater level below the bed of the river became considerably deeper (5 – 10 m depth). From Pooles Rd, upstream to Mayfield, the water table adjacent to the river was considerably higher (4 – 5 m depth). Reasons for the variation in water table adjacent to the Hinds River are as follows. At this time the Hinds River was flowing from approximately 2 km upstream of Winslow Rd all the way to the coast. In contrast, the section of river from Pooles Rd to Winslow Rd which is dominantly fed from foothills rainfall had not flowed for approximately 18 months. However the river had been flowing to approximately 1 km downstream of Hackthorne Rd from the 12 of October to the 15 of November 2005. When the Hinds River is flowing or at a higher flow the water table adjacent to the river is lifted. This explains the deeper depth to groundwater in the middle section of the Hinds River at this time.

3.5 Aquifer Properties

3.5.1 Specific capacity

Specific capacity is a measure of the productivity of a well and is determined by dividing the rate of discharge of water from the well by the drawdown of the water level in the well and is typically expressed as litres/second/meter. Specific capacity is shown for each of the five Hydrogeological Sections (identified in Section 3.2), and has been graphed at meter length intervals below ground level (Figure 3.15). The aquifers drawn in Figure 3.15 are the same as those discussed in Sections 3.2 – 3.3.

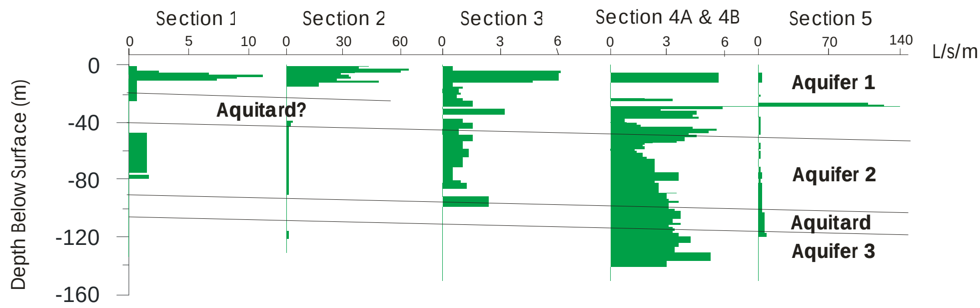

Figure 3.15 – Specific capacity versus depth for Hydrogeological Sections 1 – 5.

From sections 1 – 4, specific capacity is greatest from 0 – 15 m depth (aquifer one). The specific capacity of aquifer one in Section 2 is far higher than any other Section. However Aquidef Plots (refer to Section 3.2) show that the gravel in the upper 20 m of Section 2 is no more permeable than in Sections 1, 3 and 4. The higher specific capacity could either be due to a greater number of discrete permeable lenses, however the most likely reason is the effects of galleries. Galleries generally have higher yields and less drawdown than a single bore, and in section 2 there are 42 galleries as apposed to only 8, 11 and 1 in sections 1, 3 and 4 respectively. Sections 4 – 5 have a high specific capacity between 20 and 40 m, suggesting that the possible aquitard near the coast is absent further inland. The occurrence of aquifer two is highlighted by the increased specific capacity in section one. In section two the increased drawdown from a deep irrigation well compared with high yielding galleries makes the specific capacity look relatively low. From field work in the area, it was observed that second aquifer wells often draw down 30 – 50 m depending on the pumping rates. In section 4A and 4B, it is notable how specific capacity steadily increases from depth 60 – 140 m depth below ground level, suggesting a steady increase in permeability. This is confirmed by the Aquidef analysis which shows a steady decline in claybound and tight gravels, with a steady increase in free gravels and iron staining within this depth interval. With fewer wells drilled into the third aquifer there is insufficient data to comment on the specific capacity.

3.5.2 Transmissivity

Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient and is usually expressed in units of m^2/day. Transmissivities for wells within the study area, as obtained from aquifer pumping tests, are shown in Figure 3.16

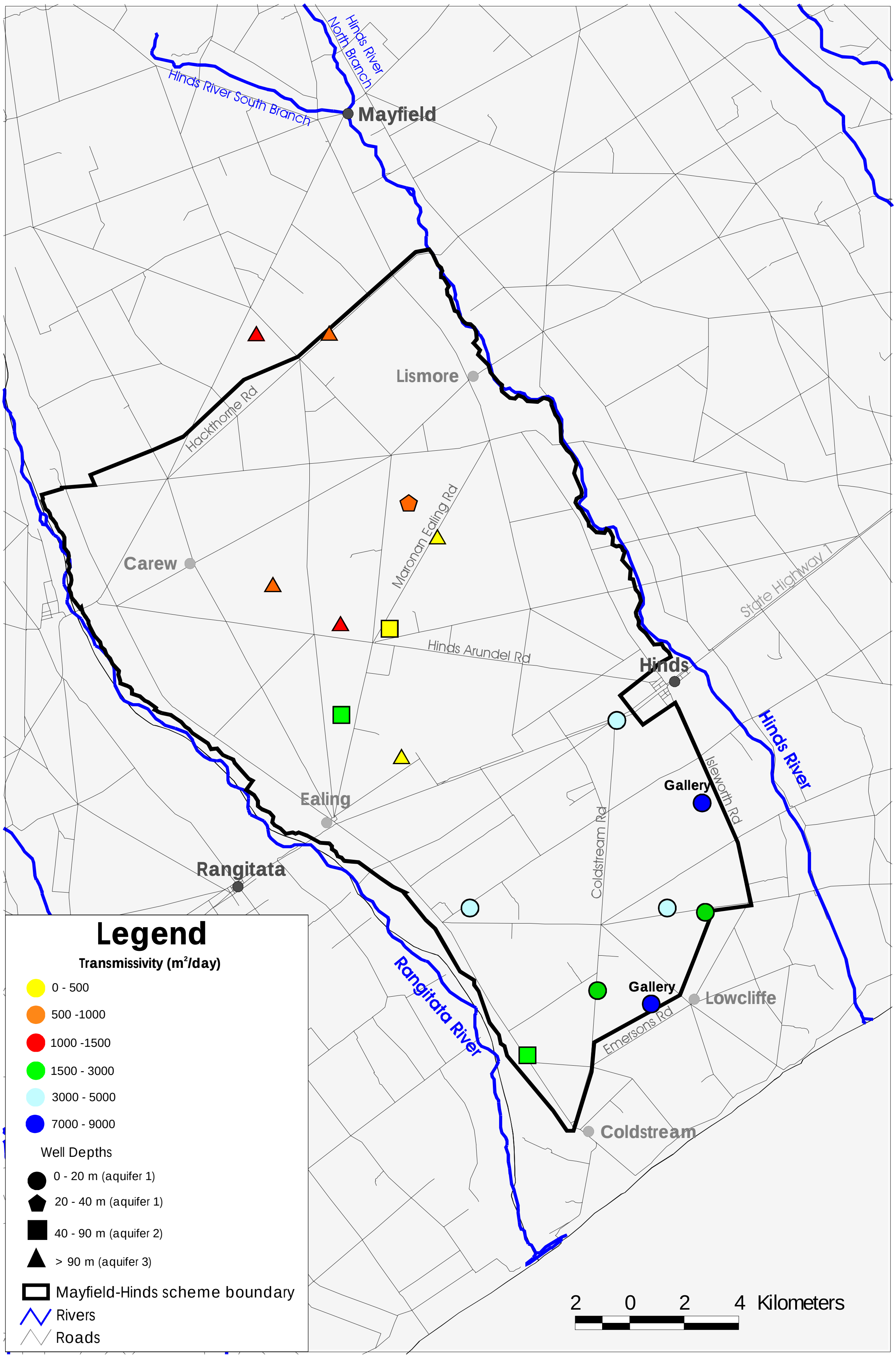

Figure 3.16 - Transmissvities for aquifer test results.

(tabulated data is presented in Appendix 3.2). Transmissivity is highest in aquifer one and ranges between 7,000 – 9,000 m^2/day from galleries and 1,500 – 5,000 m^2/day from single bores. The transmissivity of aquifer two near the coast (1,500 – 3,000 m^2/day) is similar to that recorded from single bores in aquifer one. The lowest transmissivity values of 500 – 1,500 m^2/day, were recorded in third aquifer wells, all of which were located within Hydrogeological Sections 4 and 5. However, at least half of these wells may also be screened in aquifer two. Overall there are insufficient wells with aquifer test data to determine any strong spatial patterns of transmissivity.

3.6 Groundwater Flow

3.6.1 Piezometric survey

A piezometric survey was carried out in May 2006 for a total of 146 wells (81 wells in aquifer one, 38 wells in aquifer two, and 27 wells in aquifer three). Figures 3.17 and 3.18 show the piezometric contours and flow lines for aquifers one and two. Contour lines connect static water level points of equal height above mean sea level. Groundwater flow is perpendicular to the contour lines. Aquifer three could not be accurately contoured due to insufficient water level data, and the spatial distribution of wells. The survey was carried out at the end of the 2005/06 irrigation season, meaning that groundwater levels in some areas were considerably higher due to recharge from the Mayfield-Hinds Irrigation Scheme. The effects of both scheme and rainfall recharge on groundwater flow (aquifer one only) over the course of this study is provided in Chapter 4.9.3. Details and water levels for wells used for the piezometric survey are provided in Appendix 3.3.

3.6.2 Aquifer one

Aquifer one flows from the foothills to the sea (flow lines 3 and 4), and in the same general direction as the slope of the land. Aquifer one shows a consistent hydraulic gradient of 6.2 m/km from the coast to the 190 m contour flow line. In contrast the topographic contours show a steady increase in gradient from approximately the 120 m contour line. A steady water table gradient in contrast to a steepened land surface may explain the more rapid increase in depth to

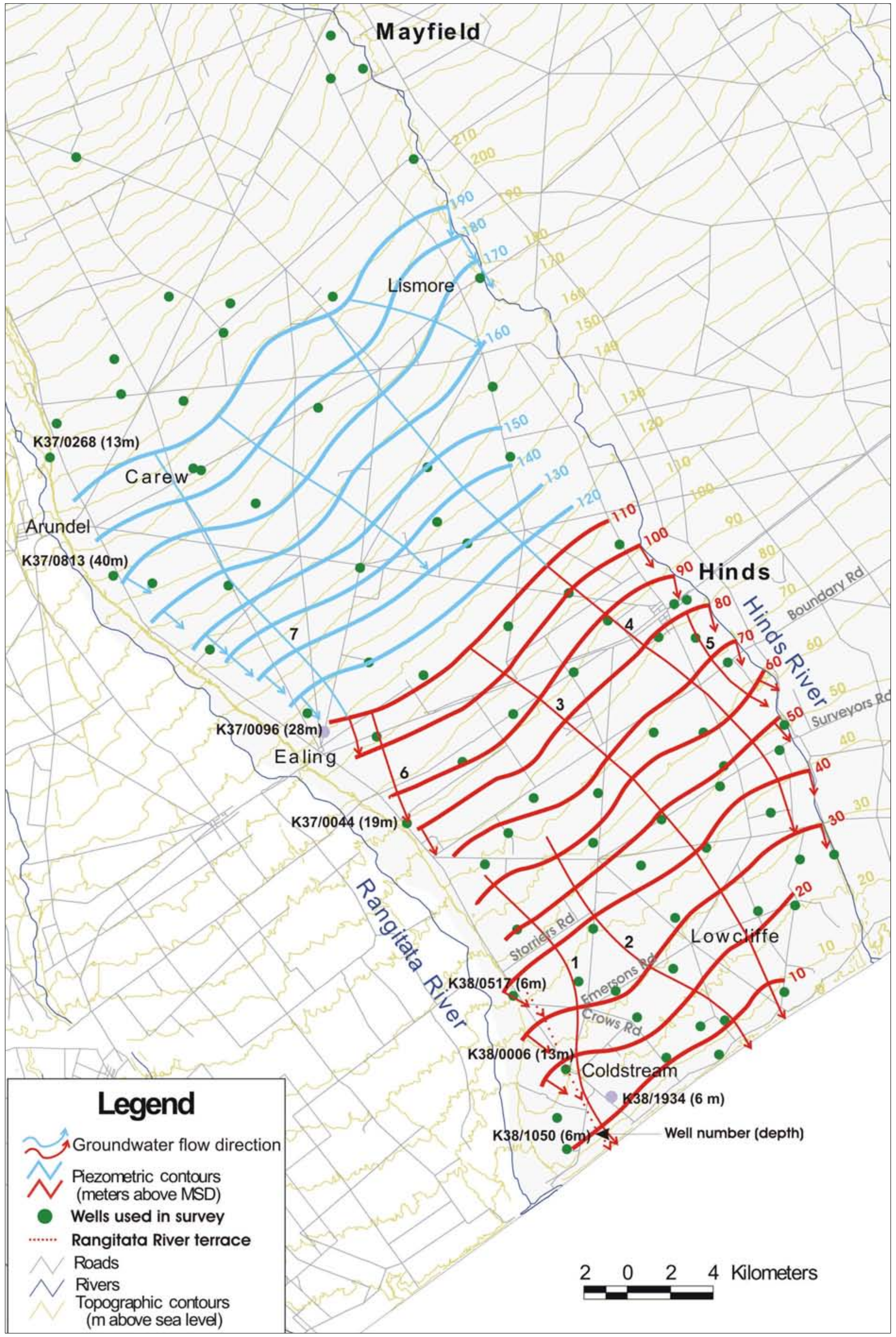

Figure 3.17 – Piezometric contours for aquifer 1. The red lines were contoured from wells less than 20 m deep and the blue lines were contoured from wells generally 20 – 50 m deep.

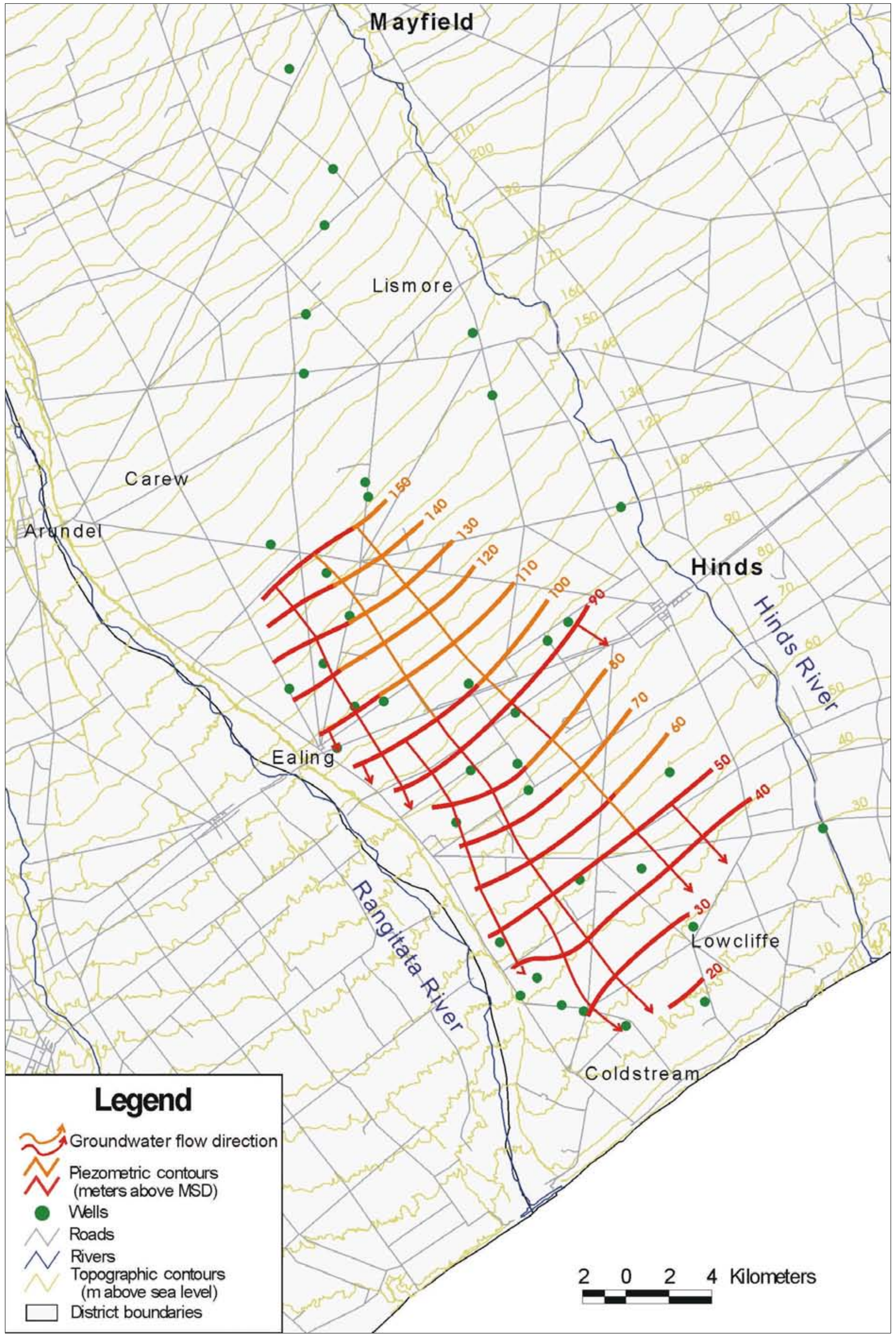

Figure 3.18 – Piezometric contours for aquifer 2. The red and orange contour lines reflect the degree of accuracy. Orange contours are likely to be less accurate as these were drawn from fewer piezometric wells.

groundwater inland from approximately the 120 m contour flow line. This inland deepening of the groundwater table is represented by the light blue contour lines, drawn from wells ranging in depth from 20 – 50 m (Figure 3.17). This contrasts from the red contour lines which were drawn from wells less than 20 m deep. The fact that the red and light blue contour lines plot together suggests that the shallow coastal and deeper inland and sections are part of the same aquifer.
It was the opinion of Oliver (1946 c) that the highest water table at the coast occurred as a result of less permeable gravels. This could be one factor, however because the upper 40 m of gravels (from Aquidef plots) are of a similar permeability and the gradient of aquifer one is less steep than the topographic gradient, the water table in this area will be highest at the coast.

The topographic contours are observed to intercept the water table at points along the 30 to 80 m contour lines. Springs are likely to occur where the two contour lines intersect. For example the 60 m water table contour line intercepts the 60 m topographic contour line near the Hinds River. This is proven in the field, as the Hinds River started flowing from groundwater fed springs (within the bed of the river) at the exact location of the 60 m water table and topographic contour lines.

The contours also show sections where Hinds and Rangitata Rivers lose surface water to groundwater, or gain surface water from groundwater inflow. Piezometric survey wells were restricted to the study area and do not extend to either side of both rivers. Had wells been surveyed on both sides of each river, losing and gaining reaches could have been more accurately defined.

From the north bank of the Rangitata River, down-gradient of K38/0517, piezometric contours show groundwater flowing out from the river. Groundwater losses from the Rangitata River are restricted to the RG2 gravel deposits (shown in Figure 2.8), the relict channels on which are clearly seen (from aerial photographs in Figure 2.7) emanating out from the northern bank of the Rangitata River. Within this area, water chemistry and oxygen-18 ($d^{18}O$) data from wells K38/0517 and K38/1050 (6 m deep) show a distinct Rangitata River water signature (Section 5). Oliver (1946 c) describes a well 800 m from the north bank of the Rangitata, with milky flood water appearing in the well, two or three days after a large flow event. He also describes water levels in a well 150 m from the north bank as being affected within a few hours, and reported that residents found the water table was higher when the Rangitata channel shifted closer to the north bank. Water level data taken from both these wells over the course of this study show a river recharge influence (Section 3.). Slightly further north, groundwater flows towards the Rangitata River (Flow line 1). Well K38/1934 (6 m deep) is located in the area where groundwater flows towards the Rangitata River and shows a distinctly rainfall recharge signature. The point where groundwater flow switches from flowing towards the Rangitata River to flowing out from the Rangitata River closely follows the Rangitata River terrace (Figure 3.17). Well K38/0006 (13 m deep) is located on the edge of this terrace at the boundary between the two opposing flow directions. Its chemistry and $d^{18}O$ signature was found to be intermediate between river and rainfall recharge.

From State-Highway 1 to K38/0517, flow lines 6 and 7 suggest that shallow groundwater flows into the Rangitata River, this feature was also noted in cross-section C - D. In addition, wells K37/0096 (28 m deep) and K37/0044 (19 m deep) do not have a Rangitata River water signature and springs which occur from the terrace adjacent to K37/0044 are reported (by farmers) to rise each summer from Mayfield-Hinds irrigation recharge. Oliver (1946 c), also believed that shallow groundwater in this area did not flow out from the Rangitata River. Between Ealing and Arundel, the contour lines end to far out from the river to say whether there are losses or gains from the Rangitata. Groundwater level fluctuations in wells K37/0268 and K37/0813 (Figure 3.17) show that Mayfield-Hinds Scheme recharge is dominant, however a distinct $d^{18}O$ and chemistry signature indicative of Rangitata River recharge was found in well K37/0813.

Flow lines 1 and 2 show an area of divergent flow, suggesting considerable surface water losses to groundwater. One potential cause could be surface water losses from irrigation lateral 4 (shown in Figure 1.13) which is located parallel to Storriers Rd (Figure 3.17) before entering the Rangitata River. Another reason could be that groundwater flow is being deflected either side of the old Hinds swamp deposits (shown in Figure 5.1), which used to end at approximately Crows Rd and Emersons Rd (Figure 3.17). Less permeable gravel deposits in this section would likely act as a barrier to groundwater flow, however no obvious differences in geology or reduction in permeability could be made.

3.6.3 Aquifer two

Aquifer two flows from the foothills to the sea, and in the same general direction as the slope of the land. In contrast to the orange contour lines, the red groundwater contour lines were plotted from more closely spaced piezometric data points. As such the red contour lines are likely to be more accurate. Aquifer two shows a consistent hydraulic gradient of 6.4 m/km, similar to aquifer one. The similar hydraulic gradient between aquifers one and two is also shown by the constant 1 – 5 m lower water level in aquifer two (refer to Figure 3.2) throughout the Hinds Rangitata Plain. The only exception is the second separate aquifer near the Hinds River, discussed in Section 3.2.5. Nearer the coast the gradient may decrease however more data points would be needed to verify this. Overall the contours are smoother and groundwater flows in less sinuous direction than in aquifer one; however more wells could change the orientation of the contours. River losses and gains can not be determined due to the absence of second aquifer wells close to the rivers.

3.7 Dry Wells

As part of an irrigation and landuse survey carried out over the entire Hinds Rangitata Plain between January and April 2006 (Dodson, 2006), landowners were asked whether wells on their property had gone dry for any period of time. The location and depths of these wells are shown in Figure 3.19. In Hydrogeological Section 1 very few dry wells were recorded, this is likely due to the smaller fluctuations in groundwater levels. In Hydrogeological Sections 2 and 3 a large number of dry wells occur between 8 and 10 m deep. Aquifer one extends to at least 20 m depth in this section and the low water levels for this aquifer occur down to at least 12 m. In Hydrogeological Sections 4 and 5 a large number of dry first aquifer wells occur between 20 and 45 m deep. Aquifer one extends to at least 50 m depth in this section and the low water levels for this aquifer occur down to at least 42 m. In Hydrogeological Sections 3 and 4, second aquifer wells between 48 and 60 m depth and two possible third aquifer wells at 88 and 94 m depth have gone dry. Aquidef plots suggest that aquifer two occurs from 40 m to approximately 70 - 90 m, whilst the two third aquifer wells may only just penetrate the third aquifer. Thus in many instances it is likely that wells have gone dry because they are not adequately penetrating the entire thickness of the aquifer.

3.8 Summary

Three aquifers are present within the Hinds Rangitata Plain. Aquifer one extends from near surface to approximately 40 – 50 m, though a possible aquitard from 20 – 40 could be present coastward of State Highway 1. Aquifer two occurs from approximately 40 – 90 m, however

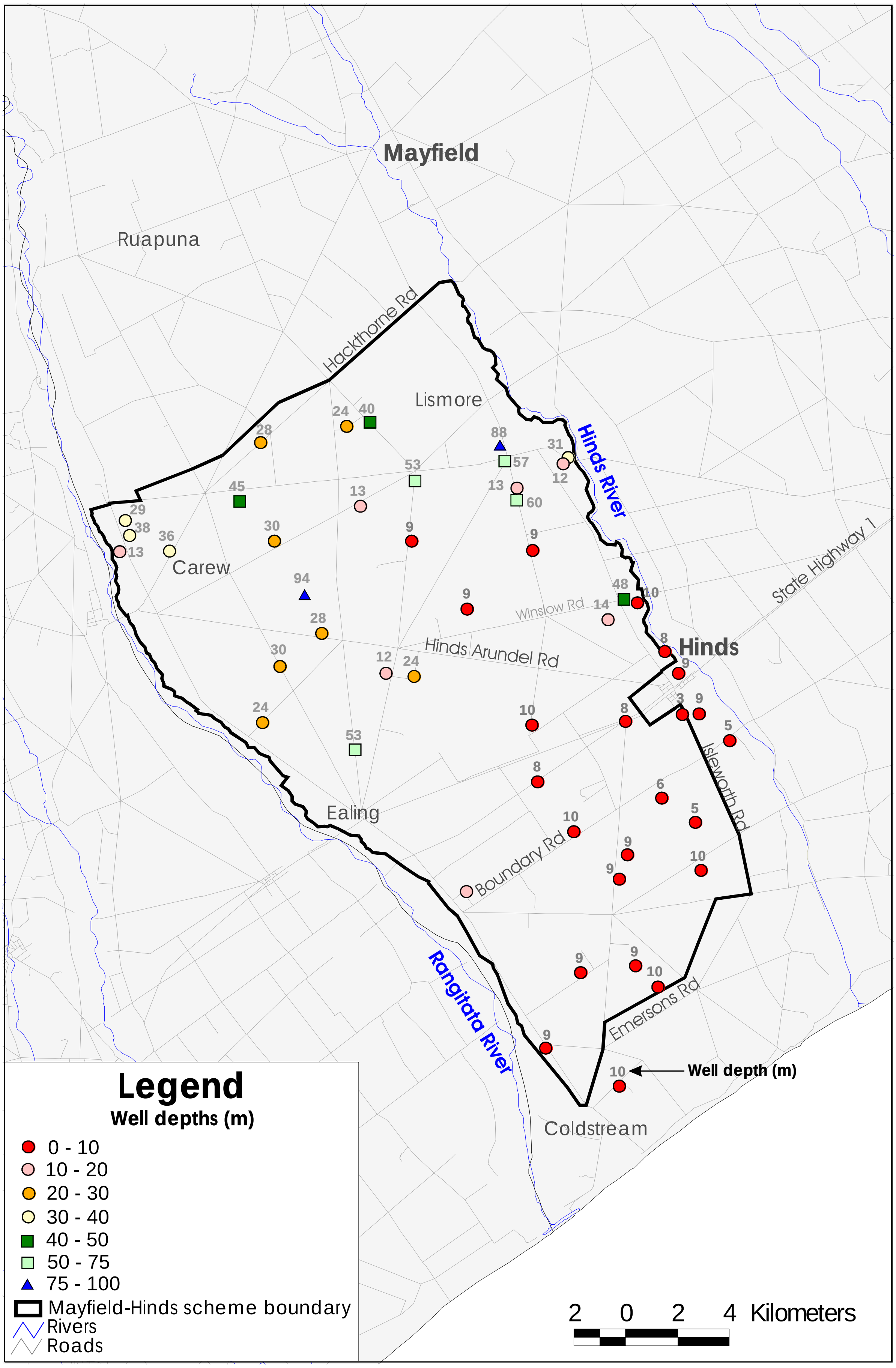

Figure 3.19 - Wells that have gone dry for a period of time (source: Dodson, 2006).

water levels suggest a separate second aquifer inland of Fountaines Rd, close to the Hinds River. Aquifer three occurs between approximately 90 and 150 m. A possible aquitard of less permeable claybound gravel occurs between 90 and 120 m depth. It is likely that dry first and second aquifer wells are not adequately penetrating the entire thickness of the aquifer.

In all three aquifers depth to groundwater increases with increasing distance from the coast, and in aquifer one (possibly all aquifers) water level fluctuations also increase with increasing distance from the coast. Aquifer two water levels are generally 1 – 5 m lower than aquifer one with the exception at the coast where water levels are higher in aquifer two, and near the Hinds River inland of Fountaines Rd where a separate second aquifer with a deeper water level is present.

Specific capacity and transmissivity is variable and often difficult to interpret when comparing galleries with wells. Groundwater flow in aquifers one and two is from the foothills to the coast. Aquifer one gains and loses groundwater along different sections of the Hinds and Rangitata Rivers, insufficient data was available to determine river losses and gains in aquifer two.

Chapter Four

Groundwater Level Fluctuations in Aquifer One

4.1 Introduction

4.1.1 Overview and objectives

Groundwater levels in aquifer one, and the recharge and discharge components of the groundwater system were monitored simultaneously over much of the Hinds Rangitata Plain. This information was used to determine seasonal water level fluctuations, sources of groundwater recharge, and the changes in groundwater flow direction over time. Long-term water level records were compared with rainfall, and Mayfield-Hinds Scheme water usage data, in order to determine the long-term water level trends. Aquifer one is the same as that identified in Chapter 3.

The main objectives of this study were to:

- Determine the effects of the Hinds River, Rangitata River, rainfall and the Mayfield-Hinds Irrigation Scheme, both spatially and with depth.
- Compare the seasonal groundwater fluctuations between aquifers one, two and three.
- Determine the groundwater response to local border-dyke irrigation and rainfall.
- Determine the effects of irrigation race losses.
- Identify gaining and losing sections of the Hinds and Rangitata Rivers.
- Compare the tidal effects in aquifers one and two near the coast.
- Compare changes in groundwater levels with the changes in flow of predominantly groundwater fed drains (refer to Chapter 6).
- Determine the changes in groundwater flow direction (spatially) for aquifer one.

Water level fluctuations are discussed in relation to the recharge responses from rainfall, border-dyke and spray irrigation, irrigation races, and the Hinds and Rangitata Rivers. In terms of discharge responses, water level fluctuations are discussed in relation to groundwater abstraction and springs. The presence and dominance of different recharge components (mentioned above) varied at different locations within the Hinds Rangitata Plain. This formed the basis for breaking the Hinds Rangitata Plain into distinctly different groundwater recharge zones.

Long-term water level records were taken from selected wells with 100 or more reading counts. The data was used to describe long-term trends and the average monthly water levels for certain zones. The details of each well is provided in Appendix 4.1

4.1.2 Groundwater recharge zones

The Hinds Rangitata Plain was broken (spatially) into seven distinct zones based on differences in the dominant source (s) of groundwater recharge within each zone. A map showing the zone boundaries and location and details of wells discussed in Chapter 4 are provided in Figure 4.1 in the text, and Figure 4.1 in the back pocket. The boundaries for each zone were determined by comparing the short-term seasonal water level fluctuations observed over the course of this study and the long-term water level records, with rainfall, river flows and Mayfield-Hinds Scheme recharge. Table 4.1 provides a summary of the groundwater recharge source (s), in order from greatest (number 1) to least dominant (number 3), is provided for each zone. In addition, the aquifers in each zone from which water level measurements were taken (over the course of this study) are also provided (Table 4.1). A summary of the water level fluctuations in each zone, and in all aquifers monitored over the course of this study, is provided in Figures 4.2 and 4.3.

Table 4.1 – Aquifers monitored and the sources of recharge for each groundwater recharge zone.

Zone	Aquifers Monitored	Sources of Recharge		
		1	2	3
1	1, 2, 3	MHIS[1]	Rainfall	Hinds River
2	1, 2	Rainfall	MHIS	-
3	1, 2	Rainfall		-
4	1	Hinds River	Rainfall	-
5	1, 2	Rainfall	RDR[2]	-
6	1	Rainfall	Rangitata River	-
7	1	Hinds River	Rainfall	-

Key

MHIS[1] Mayfield-Hinds Irrigation Scheme
RDR[2] Rangitata Diversion Race

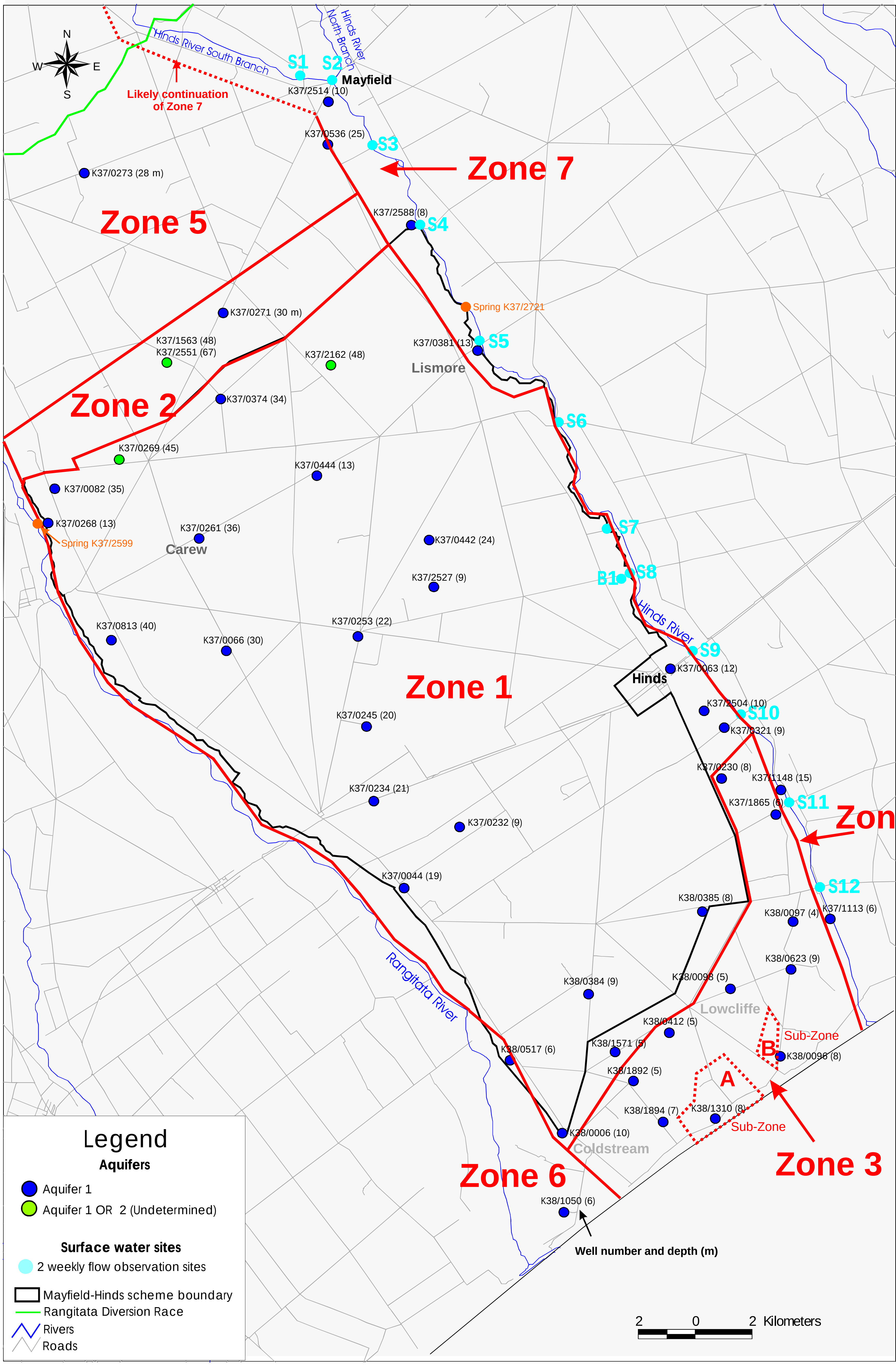

Figure 4.1 - Map showing the dominant recharge zones, the location and details of wells and springs discussed in Chapters 4, and the Hinds River flow observation sites.

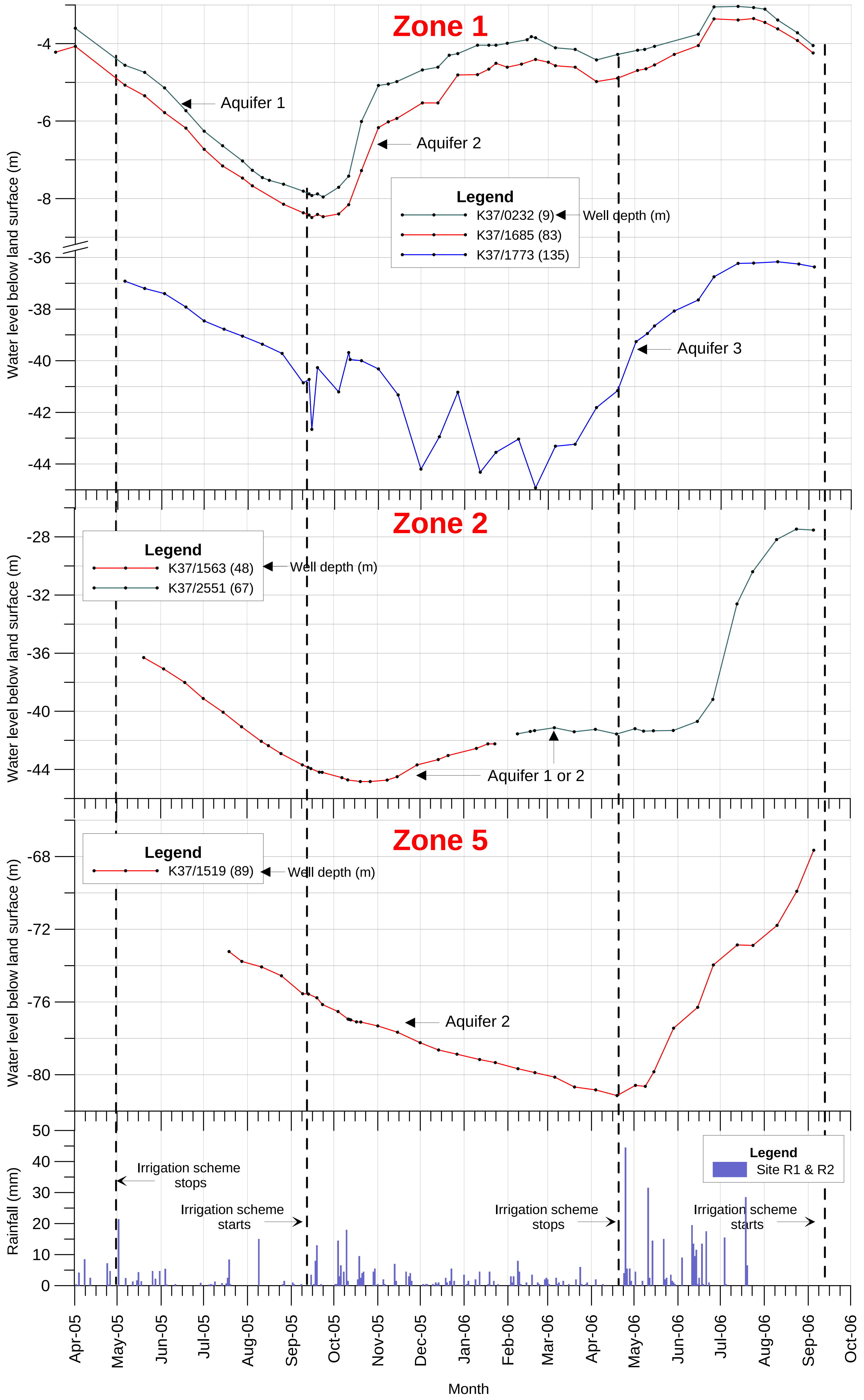

Figure 4.2 - Hydrogarphs for selected wells within each dominant recharge zone.

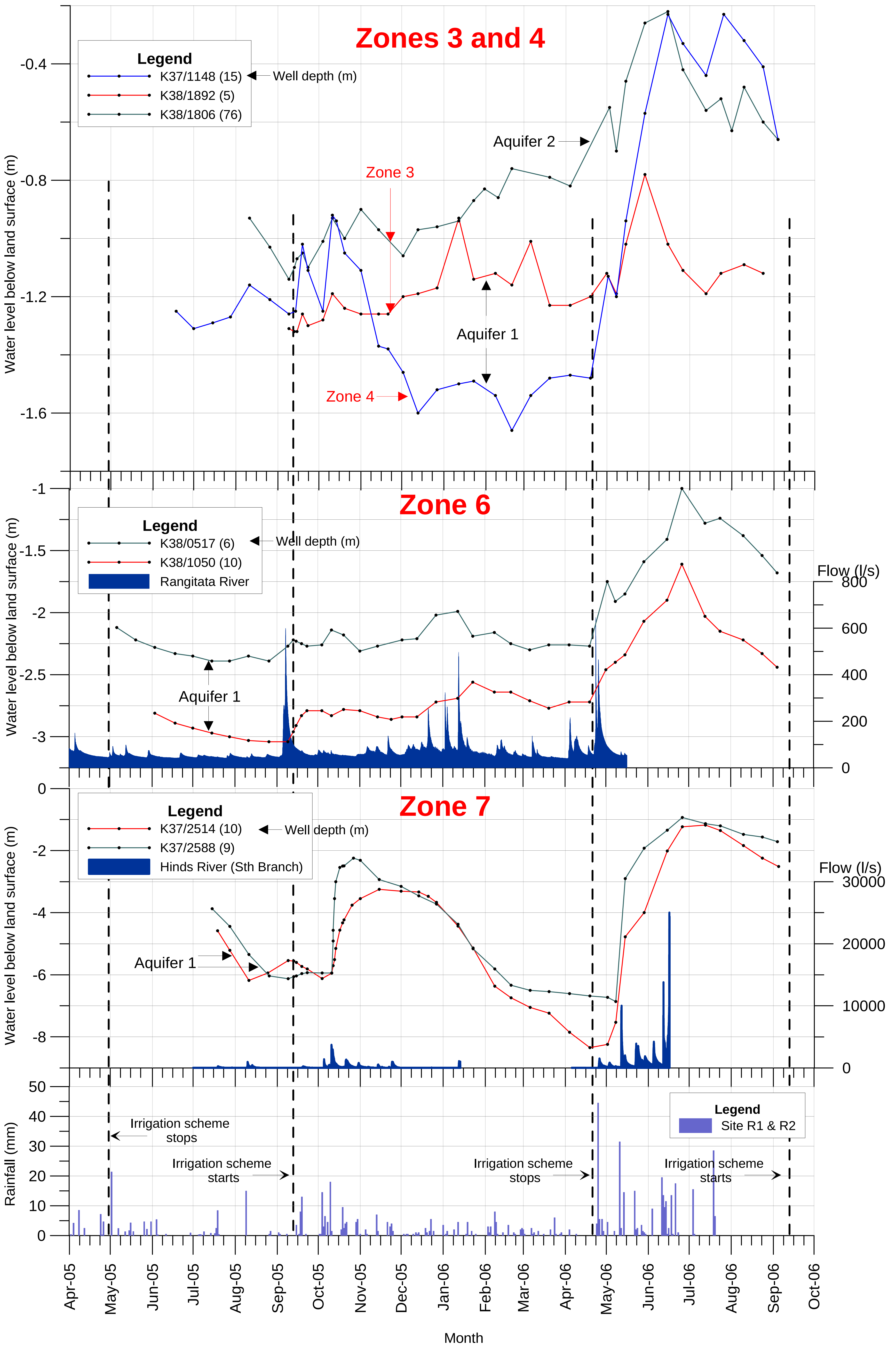

Figure 4.3 - Hydrogarphs for selected wells within each dominant recharge zone.

4.2 Methodology

4.2.1 Groundwater level monitoring network

Groundwater levels were monitored in aquifers one (48 wells), two (7 wells) and three (3 wells) from April 2005 to September 2006 in order to evaluate the short-term seasonal fluctuations and possible recharge sources to each aquifer. Water level readings were taken at two weekly intervals; in addition, automated water level recorders were also used on seven wells for various periods of time. Automated readings were taken at 30 minute intervals using Diver and Level Troll equipment. In addition monthly water level readings taken by Environment Canterbury from aquifers one (11 well) and three (3 wells) and by a landowner from one second aquifer well were also used. The location, depth, well number, and monitoring network of each well is shown in Figure 4.4. A list of the wells used and description of each provided in Appendix 4.2.

4.2.2 Groundwater recharge and discharge components

Data on the recharge and discharge components of the aquifer system is required to understand why groundwater levels rise and fall. Groundwater recharge components include rainfall, irrigation from the Mayfield-Hinds Scheme and losses from the Hinds and Rangitata Rivers. Groundwater discharge components include spring flow, drain flow and groundwater abstraction. Each of these components was monitored throughout the study. A discussion of how the data for each component was collected is provided below:

Rainfall

Three tipping bucket rain gauge sites (R2 - R4) and 1 NIWA (National Institute of Water and Atmospheric Resources) climate station (R1) were used to recorded the distribution of rainfall throughout different sections of the study area. Rainfall at each of the three tipping bucket rain gauges was collected at 5 minute intervals. The location of each rainfall site, labeled R1 – R4, is shown in Figure 1.3. When comparing the data to groundwater levels, the closest rainfall recorder site to the well (s) was used. The site used to compare rainfall with groundwater levels is identified on all well hydrographs. In order to account for local variations and the increase in rainfall inland from the coast, the three tipping bucket rain gauges were spaced in an approximate straight line from Hackthorne Rd to Coldstream Rd with a NIWA climate station recording daily rainfall at the coast.

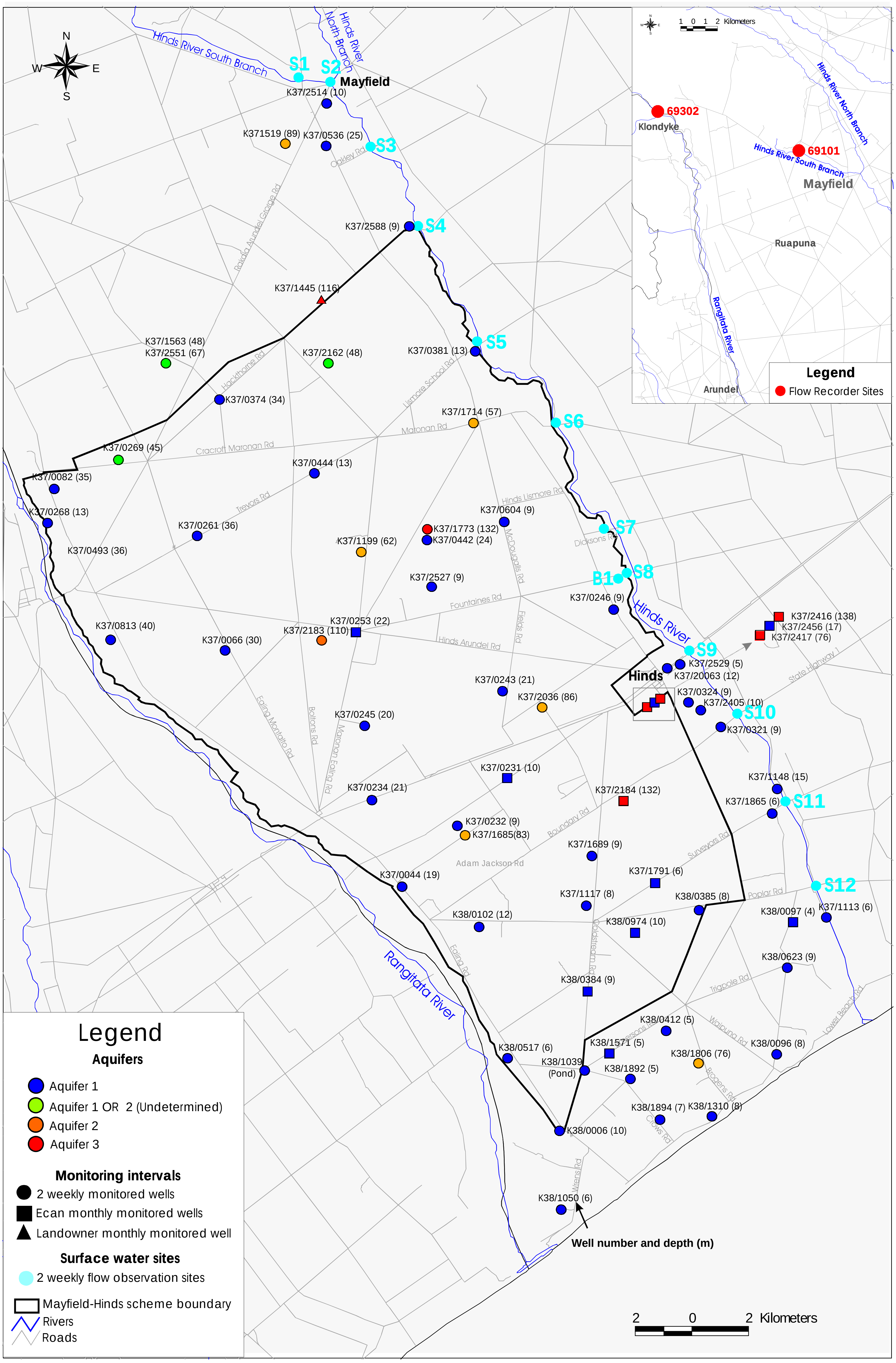

Figure 4.4 - Details for water level monitoring wells (in all aquifers) and the location of river flow recorder sites and Hinds River flow observation sites.

Historic rainfall data (> 40 years record) was collected from six different landowners within the study area. These sites are listed as L1 – L6 in Figure 1.3. A table showing the mean monthly totals from each site is provided in Appendices 1.1A – 1.1F (refer to Chapter 1.4.2).

Mayfield-Hinds Irrigation Scheme

Water usage by the Mayfield-Hinds Irrigation Scheme was based on the daily flow of water taken from the Rangitata Diversion Race. This information was provided by Rangitata Diversion Race Management Ltd.

For three wells, landowners recorded the watering dates for each paddock within their farm. The location of paddocks was provided on a farm map and the effects on groundwater levels at different watering locations around the farm were assessed.

River Flows

On the same day that groundwater levels were taken, a record of whether the Hinds River was dry or flowing was made at 12 different observation sites (labeled S1 – S12) along the length of the river from just above Mayfield-Township to Poplar Rd near the coast (Figure 4.4). In addition the flow of bywash from Irrigation Lateral 3 (Site B1) was also recorded. Photos were taken every 2 weeks at sites S11 and S12, and at every other site when the river or bywash was flowing at that location. Flow observation data was used to determine river losses and gains, recharge from irrigation bywash, effects of river flow on groundwater levels and scheme recharge effects on spring flows within and adjacent to the bed of the Hinds River. In addition, automated flow data from the Hinds River South Branch (recorder site 69101) was used to compare surface flows with groundwater levels adjacent to the Hinds River (Figure 4.4). This recorder is accurate for flood flows only, as a result inaccuracies occur at low flows. Yet despite recorder inaccuracies, correlations between the flow and groundwater levels could still be made. Rangitata River flows were taken from the recorder site at Klondyke (site 69302) (Figure 4.4). Data was plotted at hourly intervals and used to compare with groundwater levels adjacent to the Rangitata River.

Groundwater abstraction

An estimate of groundwater abstraction, and changes in abstraction over time, was based on the water usage of two center pivots. At rainfall sites R3 and R4, the tipping bucket rain gauge was located beneath the centre pivot, and each time the pivot passed over the rain gauge, the depth of water applied was recorded. These depths where then separated out from rainfall once the information was downloaded.

In two wells the pumping dates of neighboring wells were recorded to determine the hydraulic connection within and between aquifers. Pumping dates were recorded by landowners, then compared against water levels fluctuations in each of the monitoring wells.

Drain and Spring Flows

Flow data was collected from seven drains over the course of this study (refer to Chapter 6.3) and extrapolated out to all remaining drains in order to estimate the total discharge from drains over the entire Hinds Rangitata Plain. Note that virtually all spring flow is captured by these drains. Refer to Chapter 7 for a discussion of the methods used to estimate groundwater discharge in the regional water balance.

4.3 Rainfall Responses

4.3.1 Rainfall during the study

Record low rainfall occurred during winter 2005 and over the 2005/06 irrigation season. In contrast, record high rainfall occurred during winter 2006. Between April and mid September 2005 the total winter rainfall at Site L5 was 98 mm less than the mean total rainfall over this period, and the sixth lowest total in 41 years. Between April 2005 and March 2006, the total rainfall at Site L5 (25 km inland) was 230 mm less than the mean total rainfall over this period, and the second lowest total in 41 years. Rainfall Site L1 (2 km inland) was 209 mm below the mean, the second lowest total in 41 years. In contrast, between May and the end of August 2006, the total rainfall at Site L5 was 111 more than the mean total rainfall over this period and the fourth highest total in 41 years. Rainfall Site L1 was 108 mm above the mean, the third highest total in 41 years. Thus winter 2006 was one of the wettest on record.

Because all zones receive some rainfall recharge, groundwater levels in all zones were lower in March 2006 in comparison to what they would have been had there been more rainfall. The only exception is within Zone 1, where recharge from heavy summer rainfall is offset by less surface water irrigation. Consequently, water levels in Zone 1 may rise less in during a wet summer.

The following discussion looks at the different rainfall influences within each zone. Only Zones 4, 6 and 7 were excluded as river recharge was generally more important than rainfall recharge within these zones. However, a discussion of rainfall influences in each of these zones can be found in Sections 4.4.1 and 4.4.2.

4.3.2 Zone 1

Seasonal fluctuations

Winter rainfall has a significant influence on the long-term water level trends in Zone 1. Between January 2001 and December 2005, rainfall over the winter period from March – August was significantly less than the mean, whilst rainfall over summer was similar to the mean. Appendix 4.3 shows the rainfall deviation from the mean, presented as accumulated monthly totals from 2001 – 2005. The rainfall data was sourced from Sites L1 – L6. During this period groundwater levels declined more each winter as a result of lower than average winter rainfall (and from no scheme recharge), than what they rose each summer in response to dominantly border-dyke recharge. As a consequence, groundwater levels show a steady decline between 2001 and 2005.

The significance of winter rainfall is also vividly shown during winter 2005. Groundwater levels in Zone 1 are significantly affected by winter rainfall. Water levels usually decline each winter as a result of no scheme recharge, however as a result of below average winter rainfall (refer to Section 4.3.1), the water level drop over winter 2005 was significantly greater than normal. During an average winter, the water level in well K37/0253 drops 2.6 m from March to September. During the same period in 2005, the water level dropped by 5.3 m (shown in Figure 4.5). Nearer the coast, the water level in well K38/1571 drops an average of 0.5 m from May to November. Between April and September 2005, the water level dropped by 1.4 m. The greatest and most rapid drop occurred in well K37/0666 near Carew. Over a two month period the water

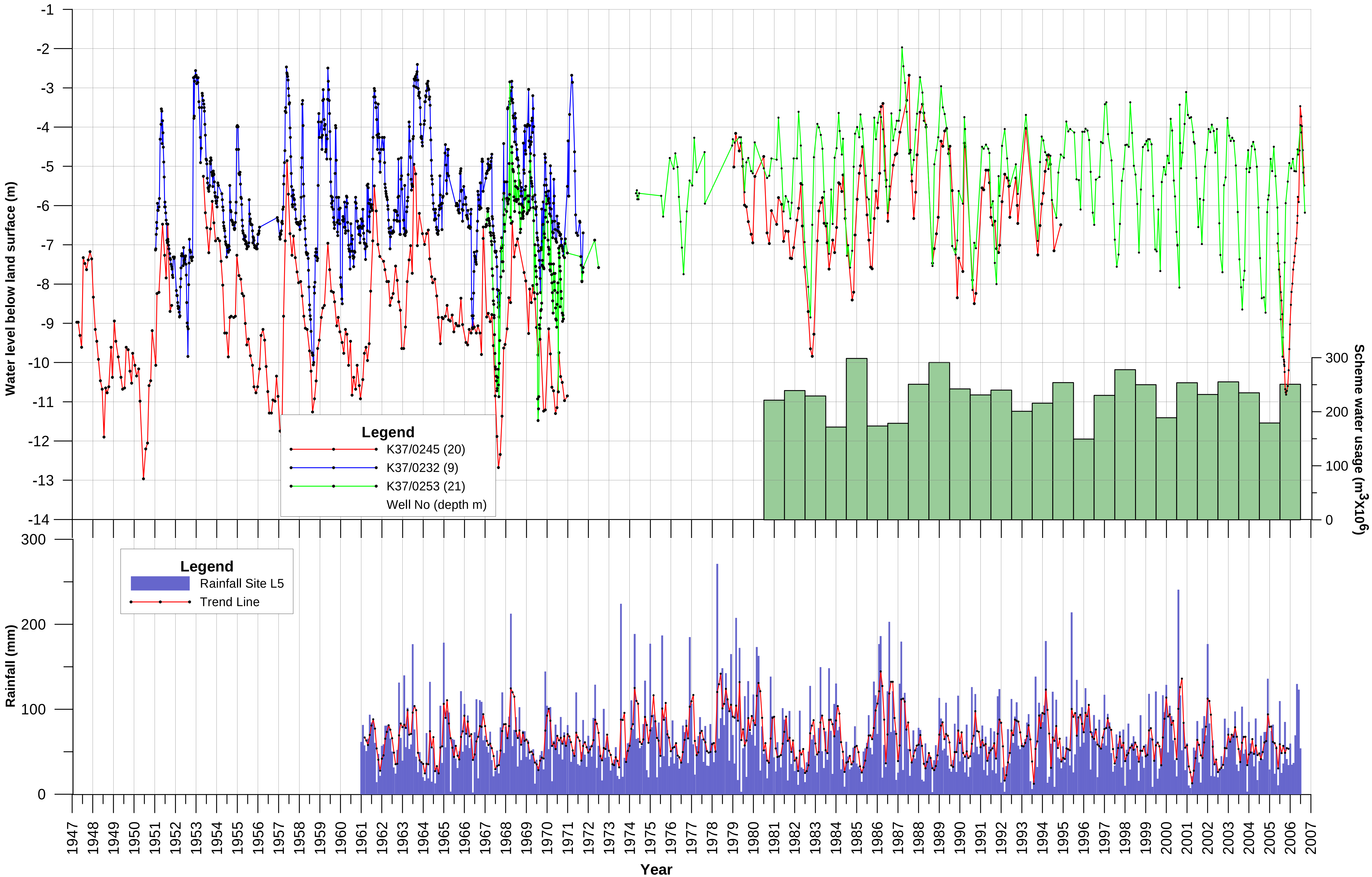

Figure 4.5 - Groundwater level history of aquifer one wells within the Mayfield-Hinds Scheme boundary. Water levels are compared with monthly rainfall data and seasonal water usage from the Mayfield-Hinds Irrigation Scheme.

level in this well dropped at an average rate of 0.85 m per week, with an overall winter drop of 8 m. Further up-gradient, coastward and north of Carew, the amount and rate that groundwater levels dropped significantly reduces. This is shown in Figure 4.6.

Groundwater levels within Zone 1 are also significantly affected by high winter rainfall, as occurred during winter 2006. This rainfall caused water levels to rise 1 – 3 m after the scheme stopped irrigating, with a general peak in July. Between July and September 2006, water levels dropped between 1 – 3 m, meaning that in many wells overall groundwater levels did not decline over winter, a phenomenon which vary rarely if ever occurs (refer to well K37/0253, in Figure 4.5). One example is well K37/0232, shown in Figure 4.2. As a consequence of groundwater levels being higher at the start of the 2006/07 irrigation season, recharge from the scheme is likely to have a greater effect on the spring and drain flows as the water table prior to irrigating, is much closer to the land surface.

Local rainfall events

Local rainfall events can cause a significant rise in groundwater over a short period of time. Within Zone 1, the water level in well K38/0385 rose more from rainfall events greater than 20 mm (during winter 2006) than from single border-dyke applications of approximately 100 mm (Figures 4.7). In Rainfall Recharge Event A (Figure 4.8), 36 mm of rain fell between 9pm (11/6) and 2pm (12/6). In response, the water level started to rise at 10pm (11/6), and by 7am (12/6) had risen a total of 56 cm. A total of 50 mm of rain fell between the 11/6 and 17/6, resulting in a total water level rise of 85 cm. During Rainfall Recharge Event A, the water table intercepted the land surface for a brief period of time. It is however, unlikely, that the water table would have intercepted the land surface without prior recharge from the Mayfield-Hinds Scheme. This illustrates the important relationship between rainfall and scheme recharge, and the resultant influences on spring flows and drainage, within the higher water table areas within Zone 1.

4.3.3 Zones 2 and 5

Up-gradient of the Mayfield-Hinds Scheme, long-term water level data from wells K37/0271 (within Zone 2), and K37/0273 (within Zone 5), suggest that Zones 2 and 5 are dominantly

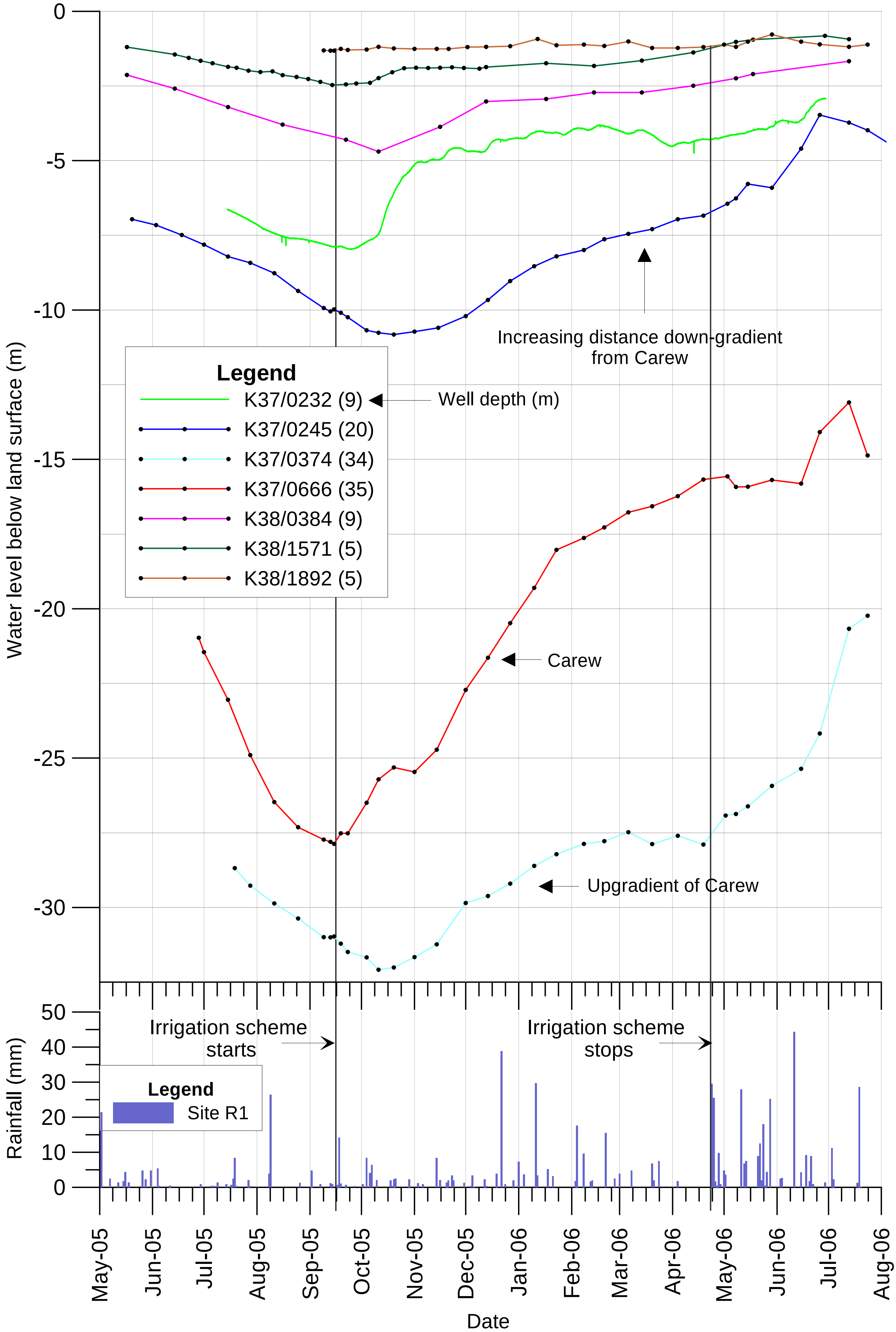

Figure 4.6 - Water level plots showing the progressive increase in seasonal water level fluctuations with increasing distance from the coastline.

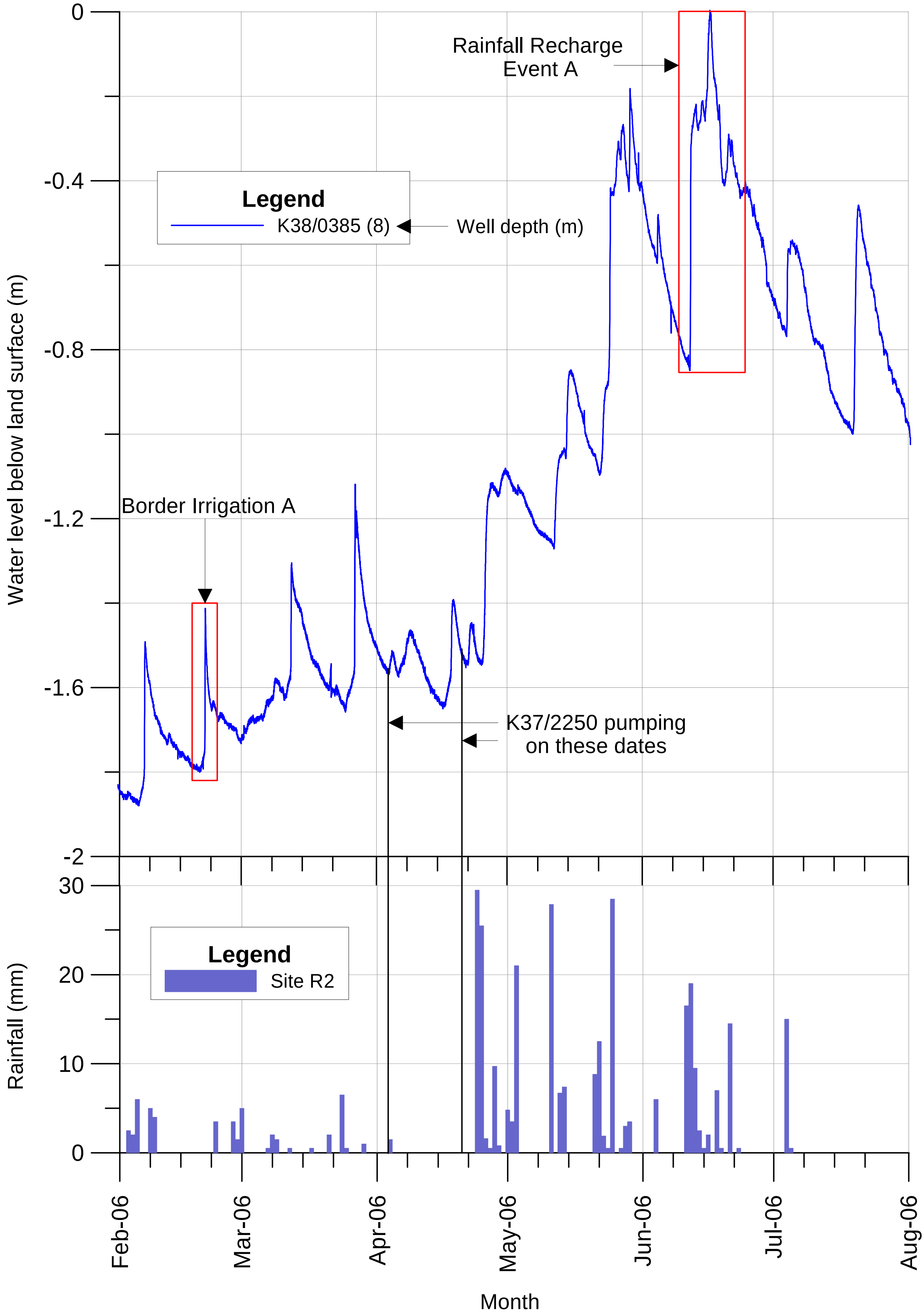

Figure 4.7 - Automated water level data from well K38/0385, showing the effects of border-dyke irrigation and local rainfall events.

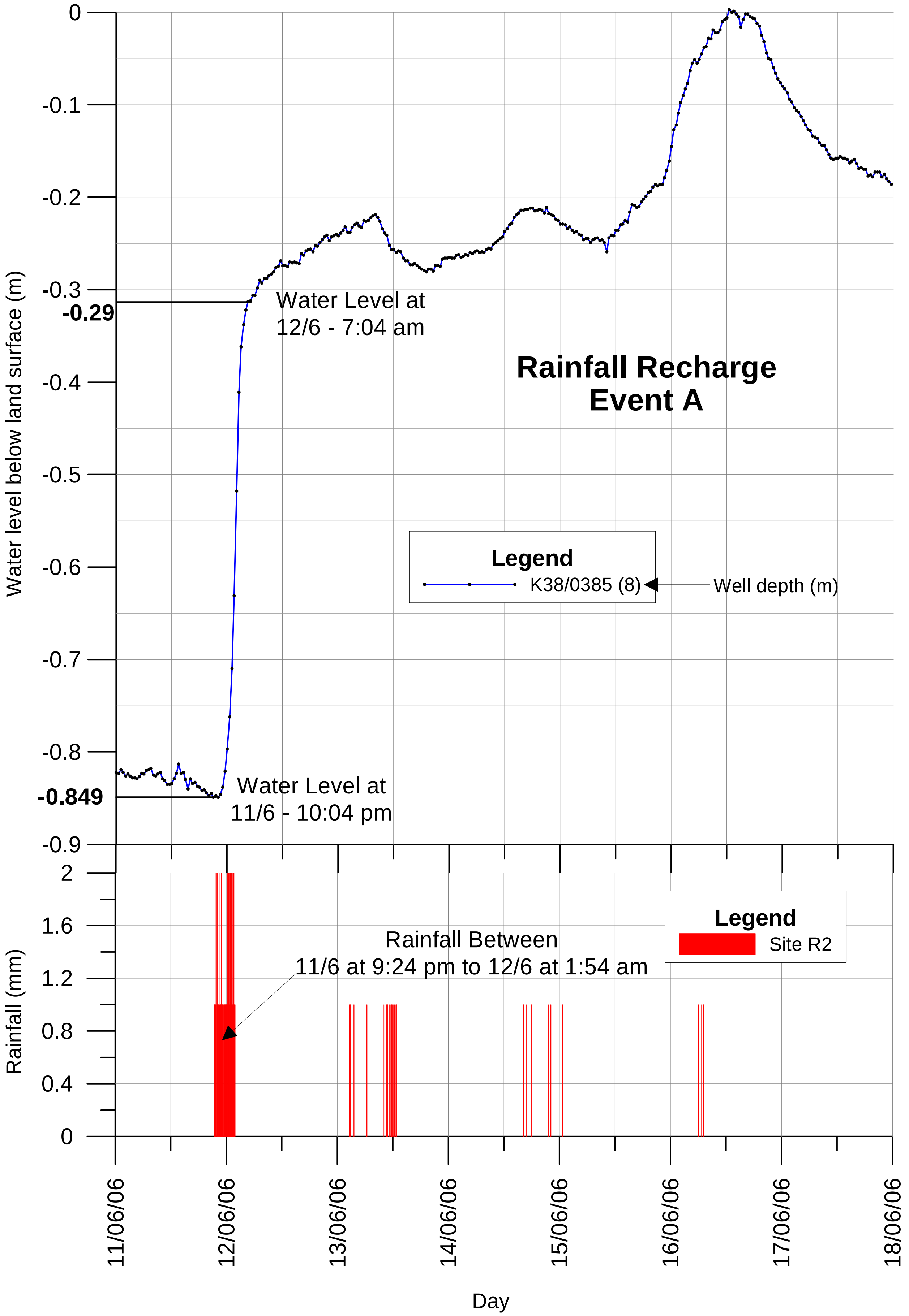

Figure 4.8 - Water level response in well K38/0385, to a large local rainfall event.

rainfall recharged. Average monthly plots show that the water levels are generally highest in winter (Figure 4.9).

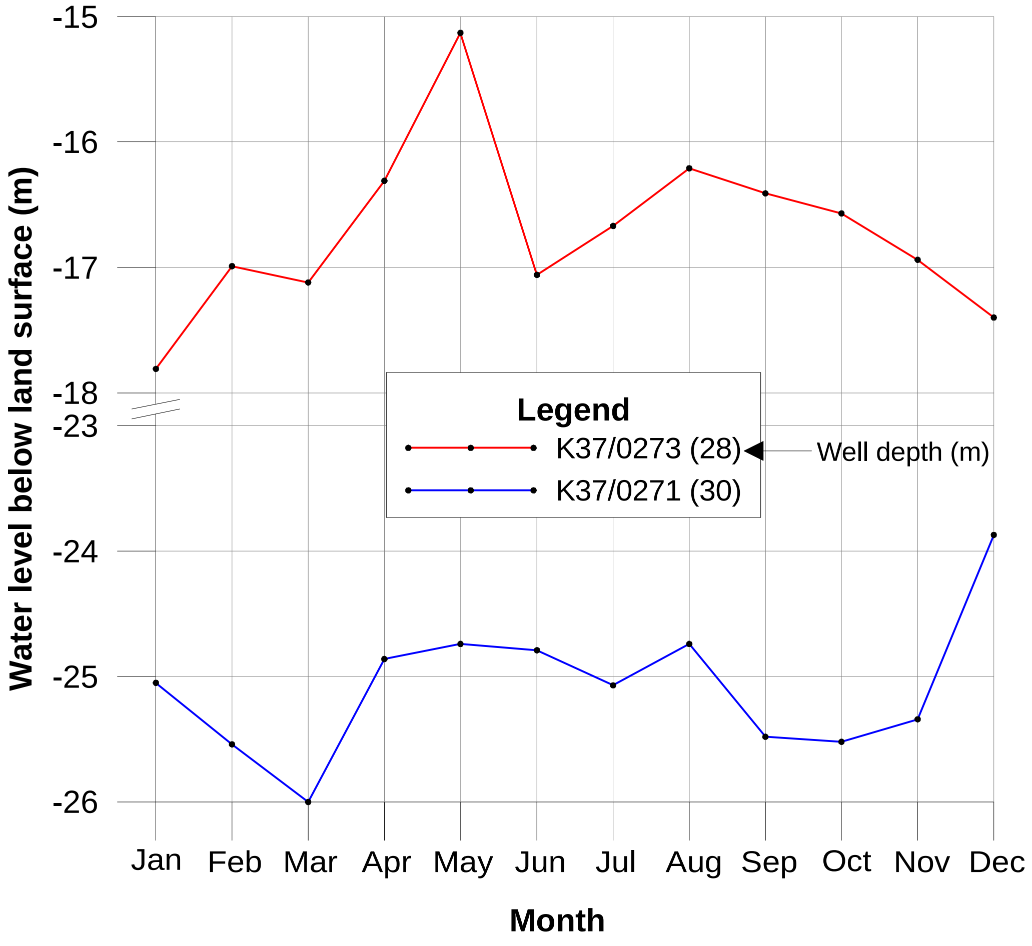

Figure 4.9 – Average monthly water level plots for two first aquifer wells up-gradient of the Mayfield-Hinds Irrigation Scheme.

This suggests a dominantly rainfall recharge influence over winter, at which time rainfall exceeds evapotranspiration (Figure 1.6). In addition, water level records from 1973 - 1995 show a correlation with the average monthly rainfall at Site L6 (Figure 4.10). Water level peaks in both wells (K37/0271 and K37/0273) generally coincide with larger rainfall months, and periods when wells went dry coincide with lower rainfall months. Many of the peaks show water level rises of between 12 to 16 m within a 1 - 2 month period (Figure 4.10). These large peaks coincide with rainfall months exceeding 150 mm.

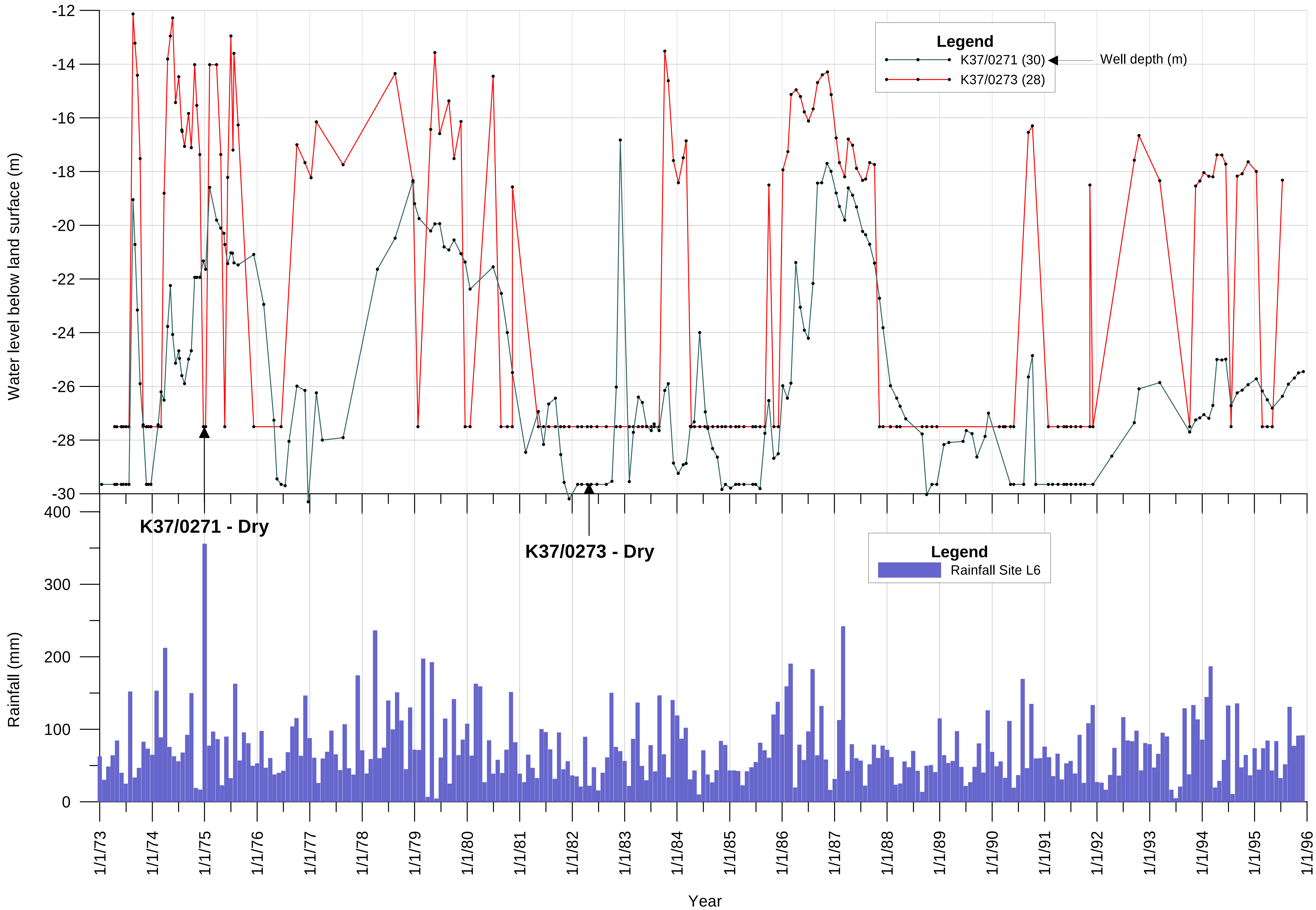

Figure 4.10 - Seasonal water level fluctuations for two first aquifer wells located up-gradient of the Mayfield-Hinds Irrigation Scheme. Monthly rainfall data taken near Mayfield-Township.

Within Zones 2 and 5, Environmental Consultancy Services (2000) and Pattle Delamore Partners (2002) also considered rainfall to be the dominant form of recharge. Despite of this, the water level in two Zone 2 wells, rose over the course of the 2005/06 irrigation season in response scheme recharge. For further discussion of these scheme induced rise, refer to Section 4.5.3, Zone 2.

4.3.4 Zone 3

Average monthly groundwater levels

Average monthly plots show an average seasonal fluctuation of 20 cm, with highest water levels in winter and lowest levels in mid summer (Figure 4.11). Well K38/0098 is 1.8 km coastward of the scheme boundary near Lowcliffe. The water level in this well is highest in July (-0.5 m) and lowest in December (-0.6 m). From December to April water levels remain stable, with a 17 cm rise from May to August. Well K38/0097 is 2 km coastward of the scheme boundary. The water level in this well is highest in July (-1.1 m) and lowest in November (-1.2 m). No obvious scheme recharge effect can be seen in this well. Well K38/0096 is 4.4 km coastward of the scheme boundary. The water level in this well is highest in August (-0.8 m) and lowest in January (-1.2 m).

There are two likely reasons why groundwater levels are highest in winter and lowest in mid summer. First, the higher winter water levels result from a delayed recharge effect from the Mayfield-Hinds Scheme. However, the only supporting evidence for this comes from oxygen-18 ($d^{18}O$) data (refer to Chapter 8.10) which is more negative than expected for groundwater this close to the coast. Second, based on rainfall at the coast being similar all year, it is likely that the rise over winter occurs when rainfall exceeds evapotranspiration. However this reason does not explain why water levels start rising between December and January. Despite un-certainty as to whether any seepage from scheme recharged groundwater occurs within this coastal area, groundwater levels, drain flows and groundwater chemistry data collected over the course of this study support the hypothesis that groundwater in Zone 3 is dominantly recharged by rainfall, with no delayed recharge effect from the Mayfield-Hinds Scheme.

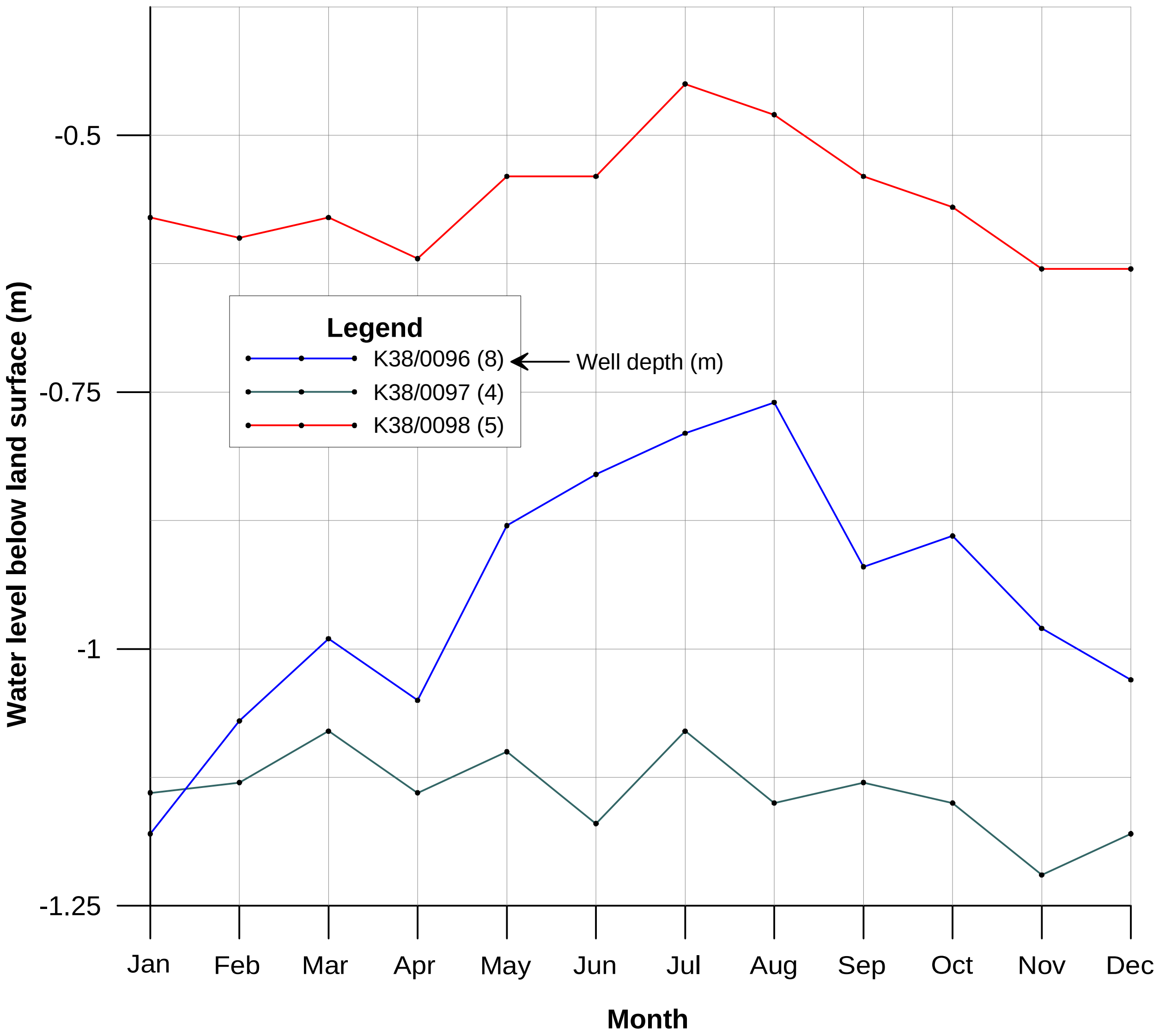

Figure 4.11 – Average monthly water level plots for selected wells in Zone 3.

Seasonal fluctuations

The following discussion looks at water changes in Zone 3, observed during the course of this study. Between May and September 2005, groundwater levels dropped overall by approximately 10 cm (Figures 4.12 and 4.13). This was likely caused by a lack of winter rainfall. 15 mm of rain on the 18 of September 2005 caused groundwater levels to rise between 5 and 30 cm. From this date onwards until approximately December, water levels dropped between 25 and 40 cm due to low rainfall. The only exceptions were wells K38/1892 and K38/1310.

The purpose of selecting wells K38/1571 (located within Zone 1), K38/1892 and K38/1894 was to look at the effect of scheme recharge with increasing distance coastward of the scheme

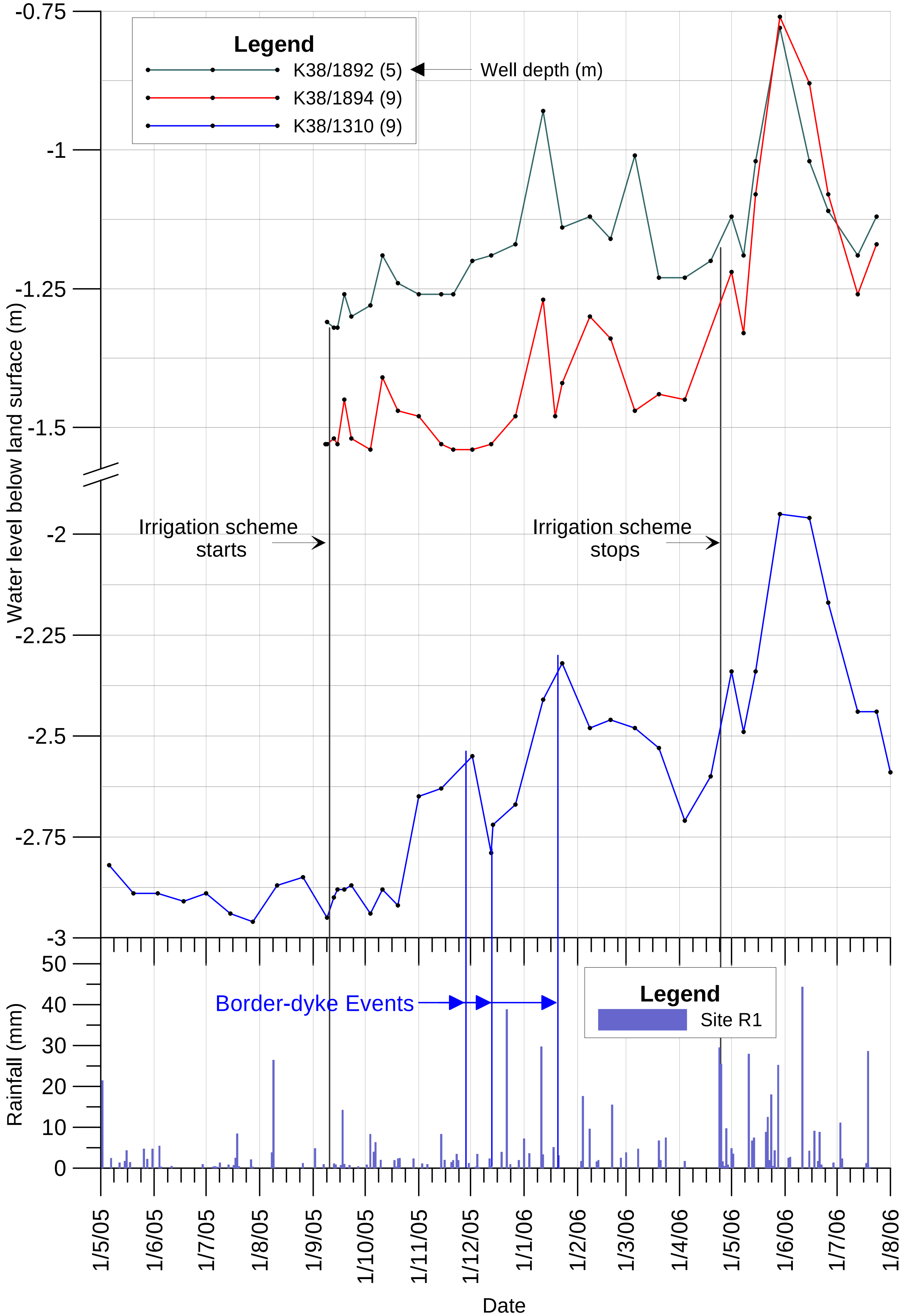

Figure 4.12 - Water level plots for selected wells in Zone 3. Well K38/1310 is located within Sub-Zone 3A as this well receives border-dyke irrigation recharge.

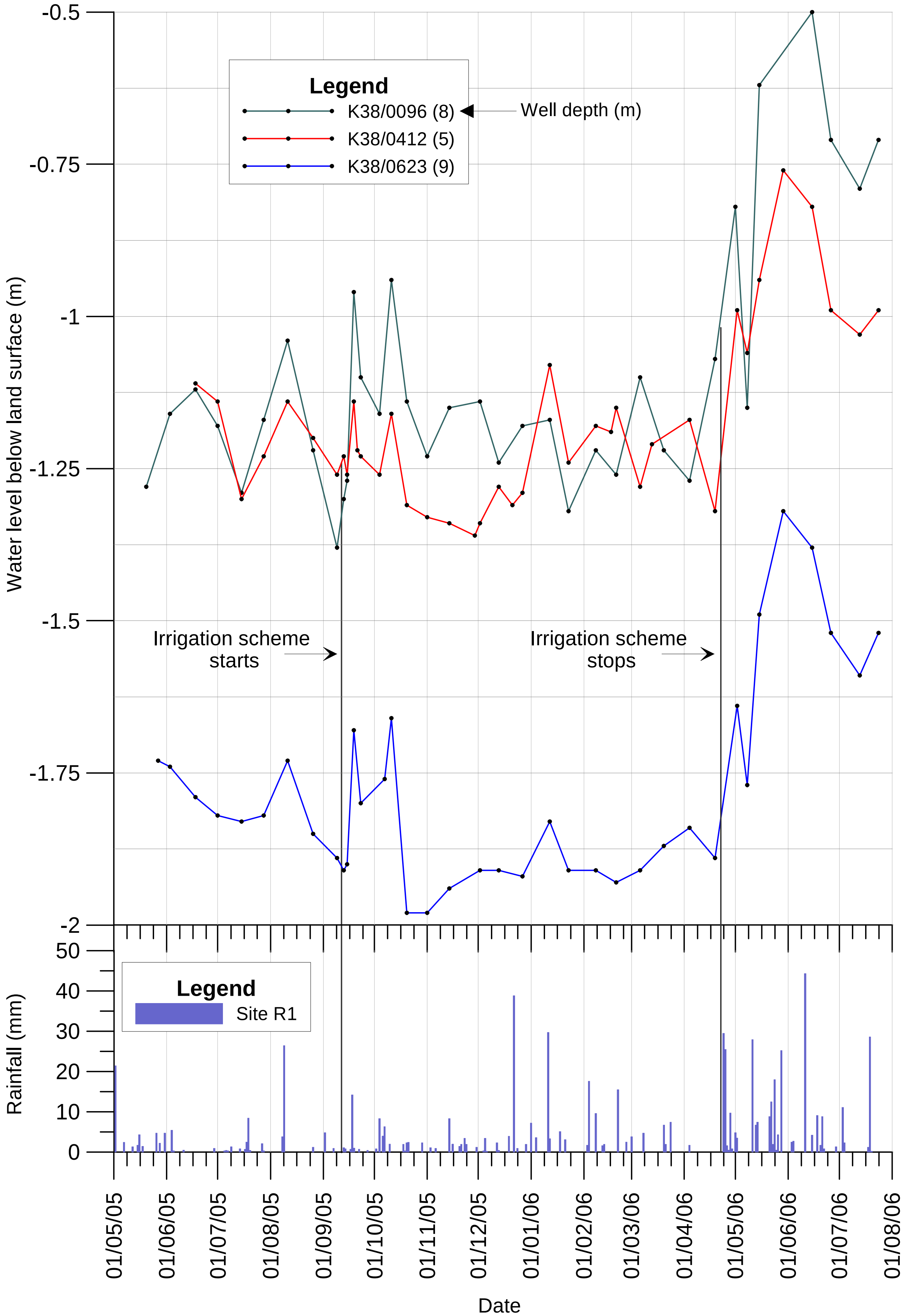

Figure 4.13 - Water level plots for selected wells in Zone 3.

boundary, in an approximate straight line. The water level in well K38/1571, on the coastward edge of the Zone 1, rose 1.1 m (Figure 4.6) over the summer irrigation period. In well K38/1892, located 1.1 km coastward of well K38/1571, a steady 14 cm rise occurred from September 2005 to January 2006 (Figure 4.12). Over this period there were no large rainfall events and 27 mm less rainfall than average (at Site L1) suggesting that the scheme does cause a very small rise in water levels at this location. 1.7 km coastward of K38/1892, the water level in well K38/1894 remained unchanged (overall) from mid September to December 2005 (Figure 4.12). This suggests that at this location there is little or no recharge effect from the Mayfield-Hinds Scheme.

Of interest was the reason why the water level in well K38/0412 dropped 22 cm between mid September and early December 2005 (Figure 4.13), despite being the same distance down-gradient of the scheme as well K38/1571. There are three possible reasons. The first is a pumping affect, however there are just as many irrigation wells close to K38/1571. The second is that the well penetrates a higher water bearing layer recharged by rainfall. This water bearing layer could be detached from deeper water bearing layers within the first aquifer (described in Chapter 6.3.2) which receive border-dyke irrigation recharge. The third and most likely reason was a lack of border-dyke recharge as a result of the nearest border-dyke paddock being 3 km up gradient of the well as opposed to 1.5 km up-gradient of well K38/1571.

In contrast to the early summer decline, water levels in all wells (with the exception of well K38/0096) rose between 10 and 25 cm in response to two large rainfall events (> 30 mm) in December 2005 and January 2006. Between April and June 2006, 275 mm of rain fell at Site L1, 121 mm above average for this period. This caused groundwater levels to rise between 45 and 76 cm (Figure 4.12 and 4.13). This is a significant water level rise for shallow groundwater this close to the coast.

One reason for little or no scheme recharge effect on aquifer one may be caused by a barrier to groundwater flow between Zones 1 and 3, such as reduced permeability of Zone 1 gravels. However, the use of Aquidef and an analysis of single bore logs, showed no discernable geological differences. Another reason could be that that springs near the boundary between Zones 1 and 3 are releasing large amounts prior to the recharge water flowing into Zone 3.

4.4 River and Race Losses to Groundwater

4.4.1 Rangitata River

Based on water level fluctuations, losses from the Rangitata River were only observed in Zone 6 near the coast. Relict channel azimuths extending NE from the river and possibly acting as preferential flow paths for groundwater, groundwater chemistry, piezometric contours and historical landowner accounts are evidence that loses from the Rangitata River occur within this zone.

A comparison of water level plots for wells K38/0517 (550 m from the river) and K38/1050 (1.7 km from the river) within Zone 6, with water level plots for two nearby wells, K38/0006 and K38/1571, in Zone 1, in addition to rainfall and flow in the Rangitata River, is provided in Figure 4.14. Wells K38/0517 and K38/1050 show small water level rises (< 15 cm) which likely occurred in response to increased river flows. However, most peaks in river flow also coincided with peaks in rainfall, making it difficult to determine the relative recharge contribution from each of the two sources. The most conclusive evidence for river recharge is shown when the water levels in both wells failed to rise in response to a 26 mm rainfall event in early August 2005, however water levels in both wells rose slightly (< 15 cm) in response to a 600 m^3/s flow event in early September 2005. Additional evidence to support river recharge is shown by the shape of the water level rise in well K38/1050 in response to increased river flow in early September 2005. This shape is similar to that of the water level rise in well K37/2514, which rose in response to Hinds River recharge in early October 2005 (Figure 4.15).

The fact that rainfall recharge events coincide with peak river flows, the large distance between well K38/1050 and the Rangitata River, and in the case of K38/0517, possible local border-dyke recharge from border-paddocks 50 m cross-gradient of the well, all make it difficult to determine how much recharge is occurring from the river. In addition, the water level rise from river recharge is a product of the river flow and the water level in the adjacent aquifer. As such, when low adjacent groundwater levels coincide with a high river flow, the water level rise will be greater. Thus had a larger flow event occurred in the Rangitata River or had the adjacent water level been lower then recharge effects from the river may have been more noticeable.

The contrasting sources of recharge is shown by the water level fluctuations from the two dominantly scheme recharged wells (K38/0006 and K38/1571) in Zone 1 which rise throughout

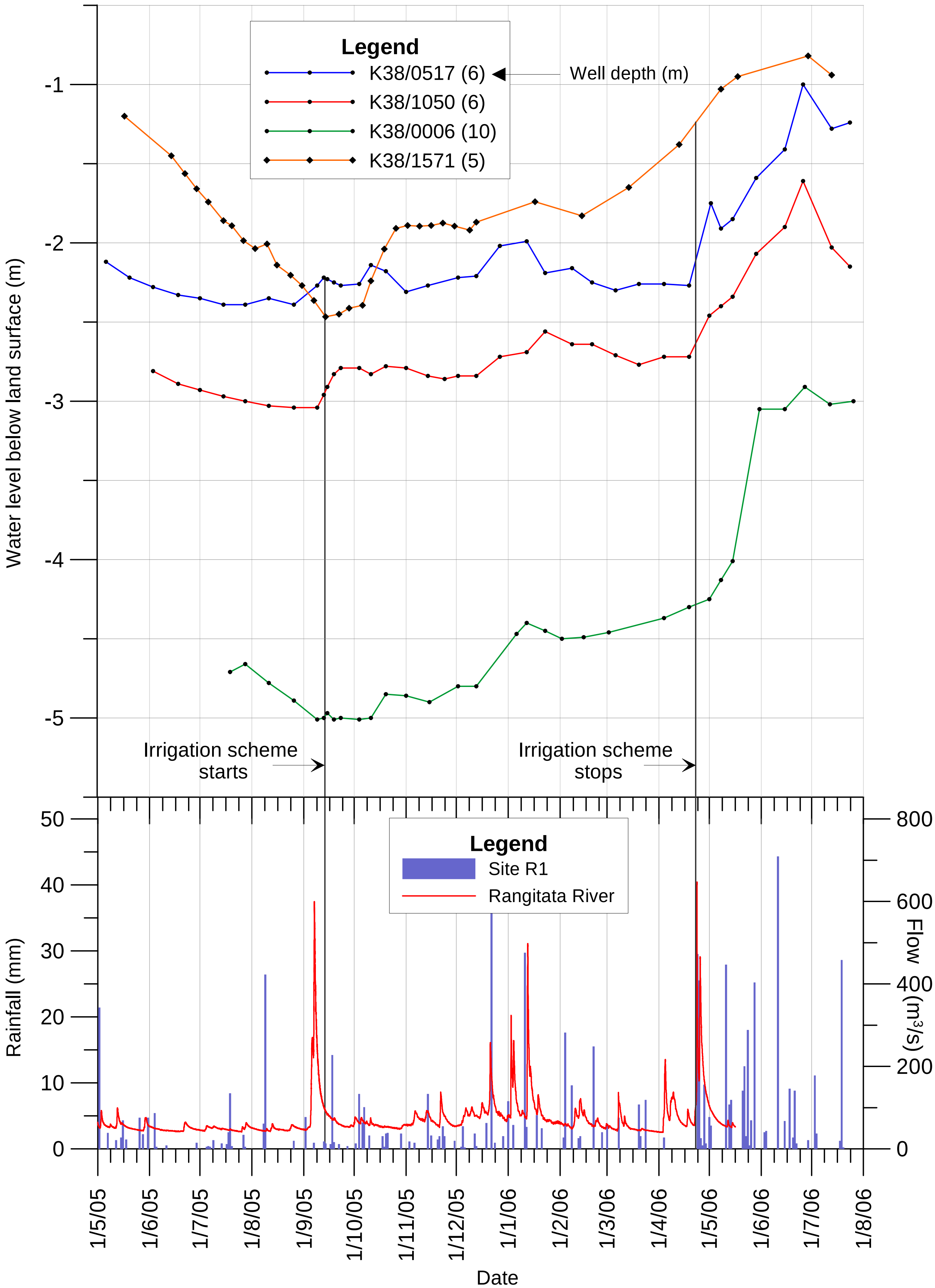

Figure 4.14 - Comparison of water level plots with rainfall and flow in the Rangitata River. Wells K38/0517 and K38/1050 are in Zone 6 and K38/0006 and K38/1571 are in Zone 1.

the irrigation season, unlike the water levels in wells K38/1050 and K38/0517 which start to decline mid way through the irrigation season. In conclusion, the data suggests that rainfall recharge is dominant with a minor contribution from the Rangitata River.

4.4.2 Hinds River

Zone 7

Groundwater level fluctuations observed over the course of this study showed significant losses from the Hinds River between Mayfield Township and 14 km downstream. Though significant losses occur over the entire length of the river (depending on the flow), unlike other sections of the Hinds River (such as the section within Zone 1), losses in this section likely account for the majority of recharge. Based on flow losses occurring downstream of Mayfield Bridge, it is likely that losses from the Hinds River South Branch also occur upstream of Mayfield Bridge (refer to dotted section in Figure 4.1). However, water levels adjacent to this section of the river were not monitored.

Water level plots for four first aquifer wells, flow in the Hinds River (South Branch), rainfall and flow dates at selected flow observation sites along the Hinds River are shown in Figure 4.15. In response to the increased river flow in early October 2005, water levels rose in all three wells closest to the river. The water level rose first in well K37/2514, 1 km downstream of Mayfield, followed one day later by well K37/2588, 6.5 km downstream of Mayfield and 6 days later in well K37/0381, 11 km downstream of Mayfield. This delay reflects the time taken for the flow in the river to move downstream. During this time, significant flow losses to the groundwater system occurred as the water table beneath and adjacent to the river rose upwards in response to river recharge. The river ceased flowing approximately 1.5 km downstream of S4 (Figure 4.1), yet a water level rise occurred in well K37/0381. This shows that the Hinds River caused groundwater levels to rise for at least 3.5 km downstream of where flow ceased. This suggests a wave of water propagating downstream in front of the surface flow. Where this wave of water intercepted the land surface, springs within the bed of the river started flowing (Chapter 6.5.3.1 Area 1).

The rate at which water levels rise and fall is reflected in the distance of each well from the Hinds River. Compared to well K37/2514, well K37/2588 is 250 m closer to the Hinds River.

As a consequence, the water level rise and fall in well K37/2588 was more rapid. Well K37/0536, 1.5 km away from the Hinds River, possibly shows a smaller delayed rise in response to an increased river flow in early October 2005. However rainfall occurring at the same time makes it difficult to determine the relative contribution from each source. McWhorter et al, 1977 describe how increases in river flow transmit a pressure wave through the aquifer, the amplitude of which decreases with increasing distance from the river. Thus the water level in well K37/0536 may have risen from a small amplitude pressure wave, with no direct recharge from Hinds River water. The falling river flow from November 2005 onwards, correlates with a drop in groundwater levels at all three wells closest to the river. In conclusion, the data suggests that Hinds River recharge is dominant with a relatively minor contribution from the rainfall.

Zone 4

During the course of this study, Zone 4 was shown to be highly affected by the Hinds River and rainfall. Water level plots for two wells in Zone 4 (K37/1148 and K37/1113), two wells in Zone 3 (K38/1865 and K38/0097), rainfall and flow dates at selected flow observations made at Site S11 are shown in Figure 4.16. The water level in wells K37/1148 (100 m from the river) and K37/1113 (60 m from the river) rose significantly in response to high river flow from May to June 2006. Prior to this period, groundwater levels dropped in response to low rainfall. This water level drop was significantly greater than in nearby wells K37/1865 and K38/0097, located in Zone 3.

Water level data suggested that a reversal in groundwater flow from towards the Hinds River, to groundwater flow away from the river occurred in response to increased flow. In October 2005 the water level in well K37/1148 was 10 cm lower than the water level in well K37/1865 (600 m from the Hinds River), suggesting minor groundwater flow towards the Hinds River. By February 2006 the water level in well K37/11148 was 75 cm lower than the water level in well K37/1865 suggesting a greater groundwater flow towards the Hinds River. As a consequence of heavy winter (2006) rainfall, flow in the Hinds River significantly increased causing the water level in well K37/1148 to rise by 1.2 m, as opposed to only 40 cm in K37/1865. This additional water level rise in K37/1148 was likely caused by losses from the Hinds River. As a consequence, the water level in well K37/1148 was 35 – 50 cm higher than well K37/1865 from June to August 2006. This may have caused a local shift in the groundwater flow direction, to flow outwards from the Hinds River. This data also suggests that recharge from the Hinds River

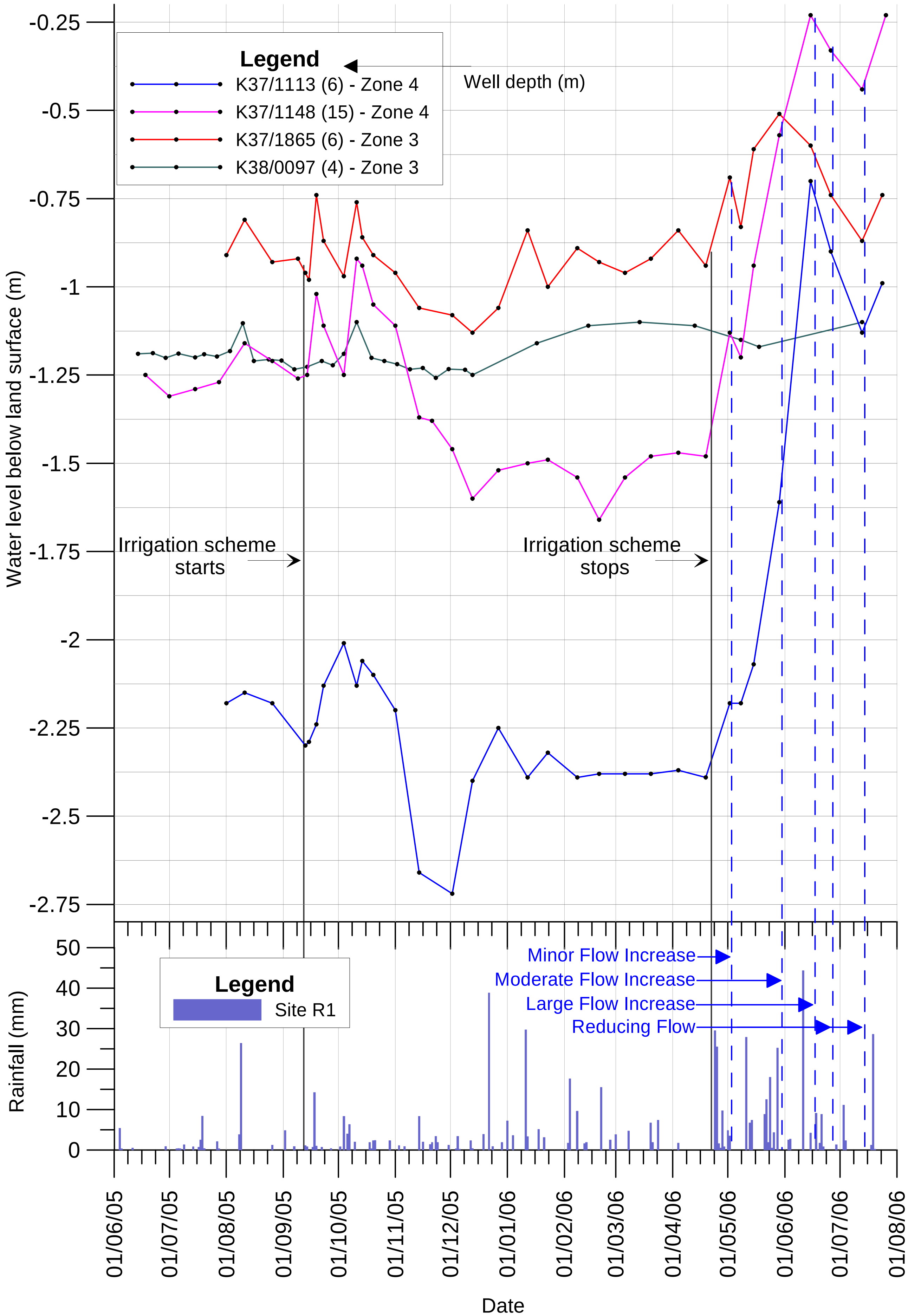

Figure 4.16 - Water level plots for selected Zone 3 wells and all Zone 4 wells.

is limited to a maximum of 600 m distance out from the River. The same change in groundwater flow direction likely occurred between wells K38/0097 (1 km away from the Hinds River) and K37/1113. Prior to April 2006 the water level in well K38/0097 was approximately 1.2 m higher than in well K37/1148. Rainfall and increased river flows in between April and May 2006 caused the groundwater level to rise by 1.5 m in well K37/1113 as opposed to only 5 cm in well K38/0097. This again resulted in the water table dropping away from the Hinds River.

4.4.3 Races

Groundwater levels in five wells all within 400 m of a main irrigation race (races shown in Figure 1.13) rose rapidly after the races were filled but peaked early and dropped steadily from approximately half way through the irrigation season (Figure 4.17). In contrast, the normal pattern for a well further from a main race, was a steady water level rise all summer, with a peak between March and April.

Water level fluctuations in wells K37/0269 and K37/0082 suggest that significant losses from the Main Race and Irrigation Laterals 1 and 2 near Cracroft occur within the first three months of irrigation. Well K37/0269 is located 70 m up-gradient of Irrigation Lateral 1, and 4.0 km up-gradient from the closest border-dyke paddock. The water level in this well rose 6.7 m before dropping in mid January.

Prior to the first water delivery to the Main Race on the 10 September 2005, well K37/0082 (northern side of the race) was dry and remained dry until the 4 of October 2005. During this period, varying amounts of air was pushed through the top of the open casing. This may have been caused by the well acting as a release valve for the rapid displacement of air within the voids of the aquifer as the groundwater level rose upwards. A visual estimate of the air being released each time the well was inspected and water flow data from the Mayfield-Hinds Scheme, showed that more air was pushed through the casing when the race was at near capacity. Assuming more air is displaced when groundwater levels rise faster then the initial rise was likely to have been rapid. The rate of water level rise declined from early October before dropping in mid December 2005. Curvature of the water level plot for well K37/0082 is almost identical to that of well K37/2514 (10 m deep), a shallow well which rises in response to increased flow in the Hinds River (Figure 4.15).

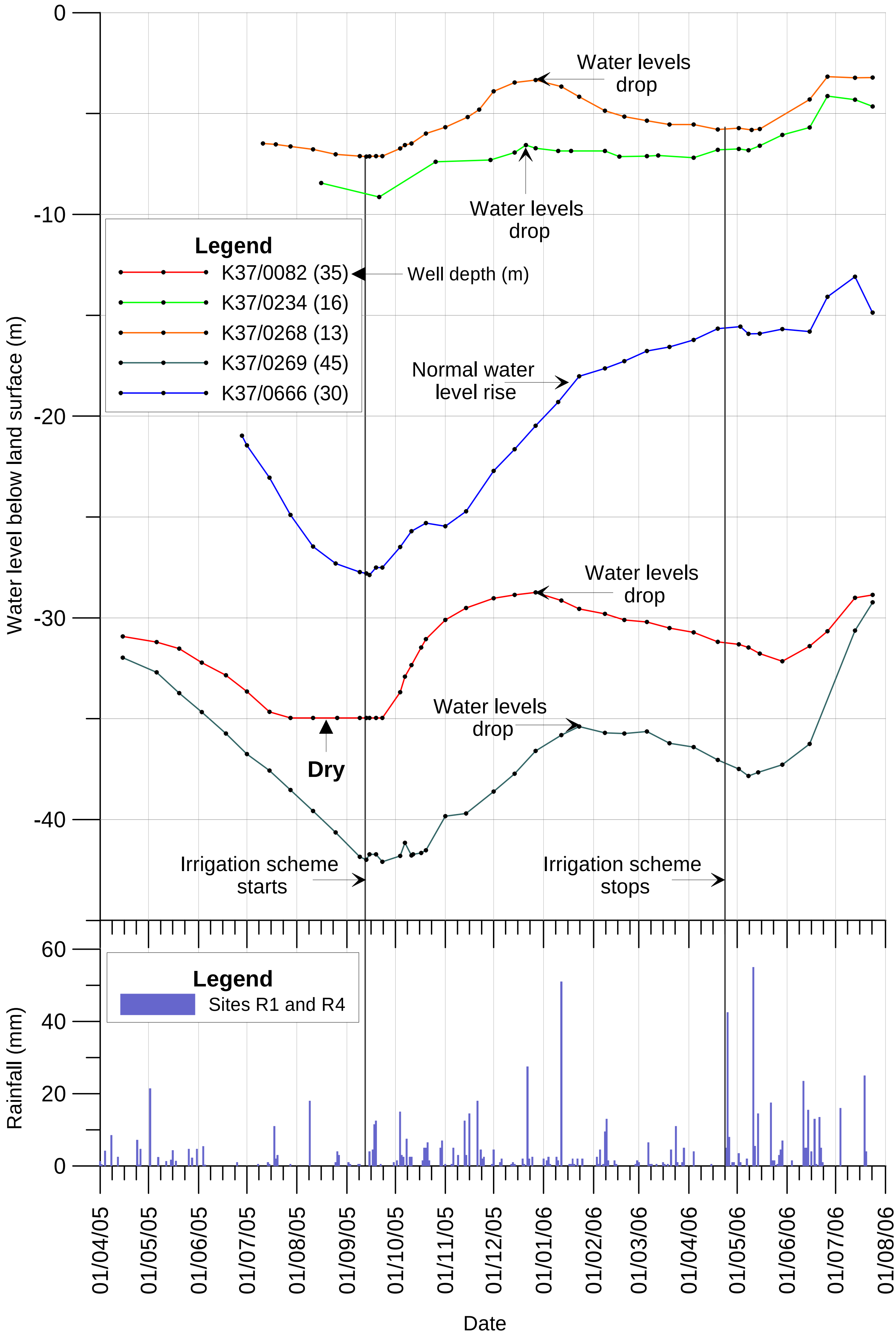

Figure 4.17 - Affects of irrigation race losses on adjacent groundwater levels.

On the basis of Hunt (1997), the progressive decline in the rate at which the water level in well K37/0082 rose, was not caused by a reduction in the hydraulic gradient between the water level in the Main Race and the underlying groundwater table. Hunt (1997) stated that a hydraulic connection between a surface body and the water table will occur when the depth to the water table below the stream surface is within five times the depth of the stream. In this case the Main Race is approximately 2 m deep, meaning that a hydraulic connection will occur when the water table rises to within 10 m of the land surface. Well K37/0082 is located on a terrace approximately 10 m higher than the Main Race. Thus at the start of the irrigation season the water table was lower 25 m below the land surface, and at its peak the water level rose to within 18 m of the land surface. This suggests that losses from the Main Race were solely caused by a gradual sealing of the race over time. This was likely caused by silt sourced from the Rangitata River being deposited within the bed of the race.

The water level rise in well K37/0268 (13 m deep) on the southern side of the Main Race was almost identical to that of well K37/00082 (35 m deep), suggesting these wells are hydraulically connected if not in the same aquifer. In mid September, the water level in K37/0268 was -7.50 m below ground level and as such the groundwater table sloped down to the well away from the Rangitata River suggesting river recharge (Figure 4.18). By mid December the groundwater level had risen to -3.7 m below ground level causing the water table to slope down from the well to the river. This suggested groundwater flow towards the river.

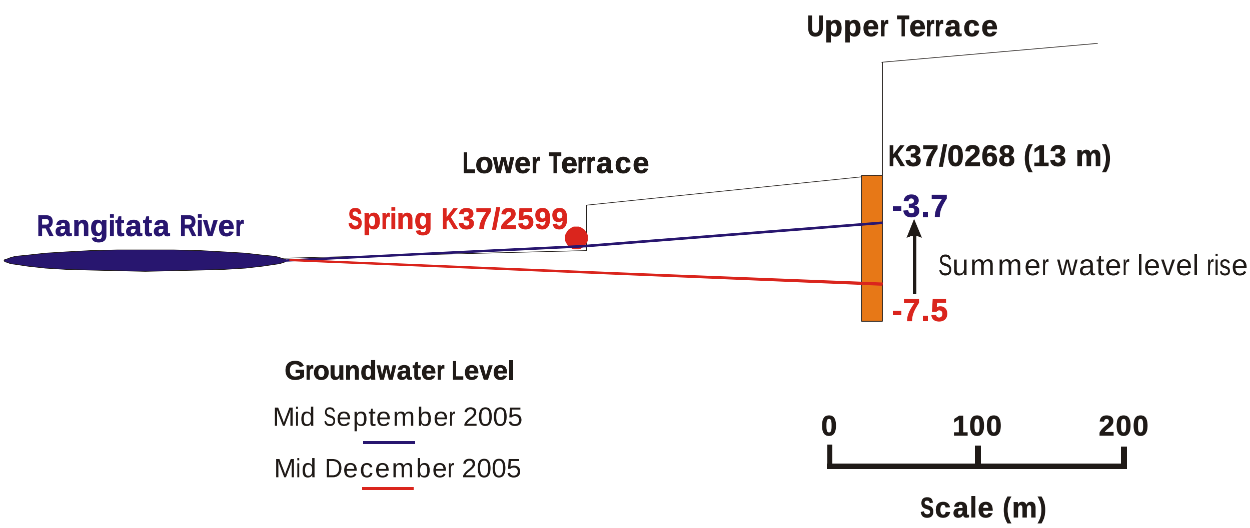

Figure 4.18 – Schematic cross-section of aquifer 1 near the Rangitata River at Cracroft (Eleven times vertical exaggeration).

Additional evidence for a combination of river and scheme recharge was provided by the owner of well K37/0268 who described the pattern of flow from spring K37/2599 (refer to Figures 4.1 and 4.18) at the base of the lower terrace over the past 20 years. According to the landowner, this spring used to go dry during the winter but was active in the summer, suggesting a recharge effect from the Mayfield-Hinds Scheme. During this study, the flow from this spring increased between late September and early November 2005.

In addition, the landowner noted that spring K37/2599 historically went dry in winter, however this has not occurred in the last 6 winters. One possible reason why the spring has not gone dry despite below average winter rainfall over the last 4 years could be a shift in the Rangitata River channel closer to the north bank. Long-term groundwater level rises adjacent to the Rangitata River attributed to shifts in the river channel are recorded by Oliver (1946 c) near Coldstream, and a landowner approximately 4 km downstream of the Hinds Arundel Bridge, spoken to during the course of this study.

4.5 Border-dyke and Spray Irrigation

4.5.1 Water level history within Zone 1

Unfortunately, there are no long-term groundwater level records prior to the first water delivery by the Mayfield-Hinds Irrigation Scheme in 1948. Thus it is impossible to exactly determine the natural groundwater levels and seasonal fluctuations within the scheme boundary. Wells K37/0245 and K37/0232 (Figure 4.5) have a combined long-term water level record from 1947 to 1971. Initial uptake of scheme water was slow, with only 20 % of the scheme area was irrigated by 1975. As a result, these wells provide some insight into the natural pre-irrigation groundwater system. From 1947 - 1971 these two wells show a predominantly rainfall recharge influence with peaks in water levels coinciding with peaks in rainfall, and dry periods coinciding with lower water levels (Figure 4.5). During this period, average monthly water levels from well K37/0245 show a 1 m rise from September to April, and a slight overall drop from May to August (Figure 4.19).

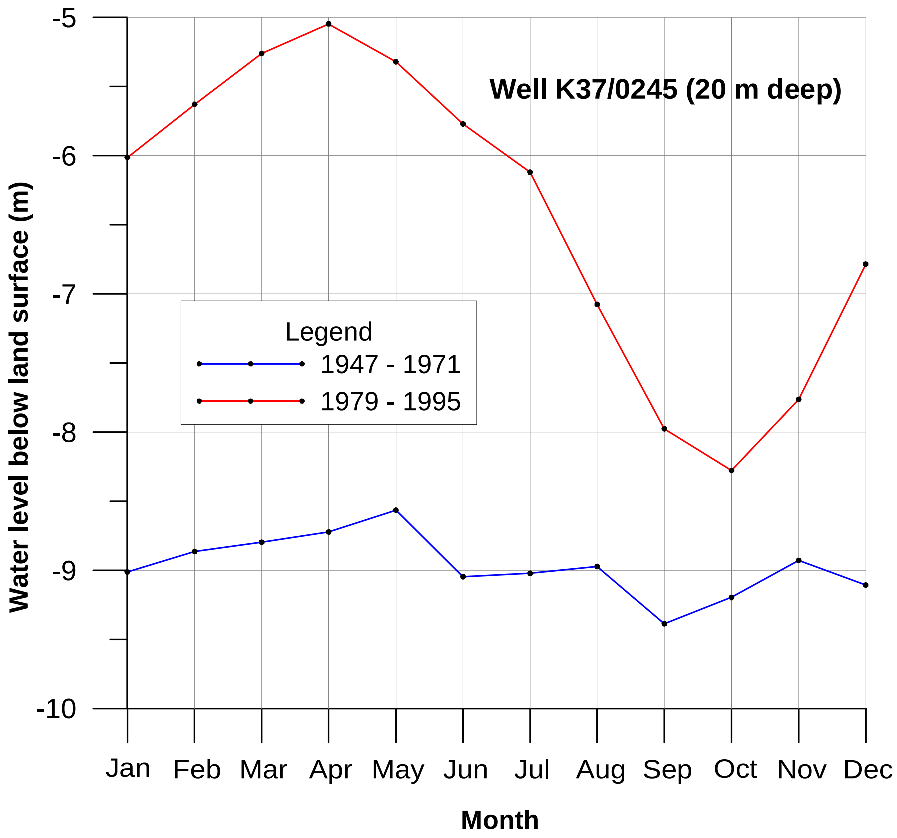

Figure 4.19 – Average monthly groundwater levels for well K37/0245 over two separate time periods.

This summer water level rise may have been caused by a relatively small quantity of irrigation recharge as would likely occur from the small area (less than 6,000 hectares) irrigated at this time. It is unlikely that the summer water level rise resulted from rainfall recharge, as rainfall only exceeds evapotranspiration during winter. During this early period of time, irrigation recharge likely reflected the degree of irrigation development within different areas of the scheme, with wells close to border-dyke paddocks showing a greater summer rise.

From mid 1978 onwards, groundwater levels were again recorded from wells K37/0245 and K37/0253. The mid 1978 water level in K37/0245 was 6 m higher than at the end of 1970, and in K37/0253 the groundwater level was 3 m higher than in mid 1972 (Figure 4.5). From 1971 to 1977 the annual rainfall at Site L5 was 9 mm higher than the average (790 mm) and an additional 10% of the total scheme area was being irrigated by the end of this period. Increased scheme recharge would have contributed to this rise, however the main cause is attributed to the 270 mm of rain which fell in April 1978, 200 mm more than the average for that month and the highest monthly rainfall total ever recorded at Site L5.

In comparison to pre 1972 groundwater levels, the average post 1978 (1978 to 2006) groundwater levels in wells K37/0245 and K37/0253 rose from -8.9 to -6.4 m below ground level and -7.2 to -5.2 m below ground level respectively. Since 1982, the groundwater level in well K37/0253 has been consistently highest in late summer and lowest in spring. This would be expected with 80 % of the scheme area irrigated by this time. Since 1982, irrigation recharge has caused groundwater levels to follow a very similar seasonal pattern each year.

4.5.2 Seasonal fluctuations within Zone 1

On average, groundwater levels are highest from March to May, and lowest from September to October (Figure 4.20). Note that the Mayfield-Hinds Scheme have consent to irrigate from the 10 of September to the 10 of May. Well K37/0253 (22 km inland) rises approximately 3 m from September to March. Closer to the coast, well K8/0384 (7 km inland) rises approximately 1.75 m from October to April. Down-gradient of the Mayfield-Hinds Scheme, well K38/1571 (4 km inland) rises approximately 0.5 m from November to May. This shows how the rise in water table closer to the coast is reduced in magnitude and lags in time.

4.5.3 Regional border-dyke recharge effects

Zone 1

As a consequence of low summer rainfall, the Mayfield-Hinds Scheme used the total available water for almost the entire 2005/06 irrigation season. Note that the total available water varies with daily restrictions on the Rangitata and Ashburton Rivers. Progressive restrictions occur when flows drop below a certain level. Surface take restrictions over 2005/06 were typical of a normal irrigation season. With high demand caused by low rainfall, the total seasonal water usage was above average, and the seventh highest total in 26 years. As a consequence, water levels rose significantly over the summer period as evident in well K37/0253 (Figure 4.5) Over a normal irrigation season the water level in well K37/0253 rises 2.6 m, in contrast the water level rose by 4.7 m over the 2005/06 season.

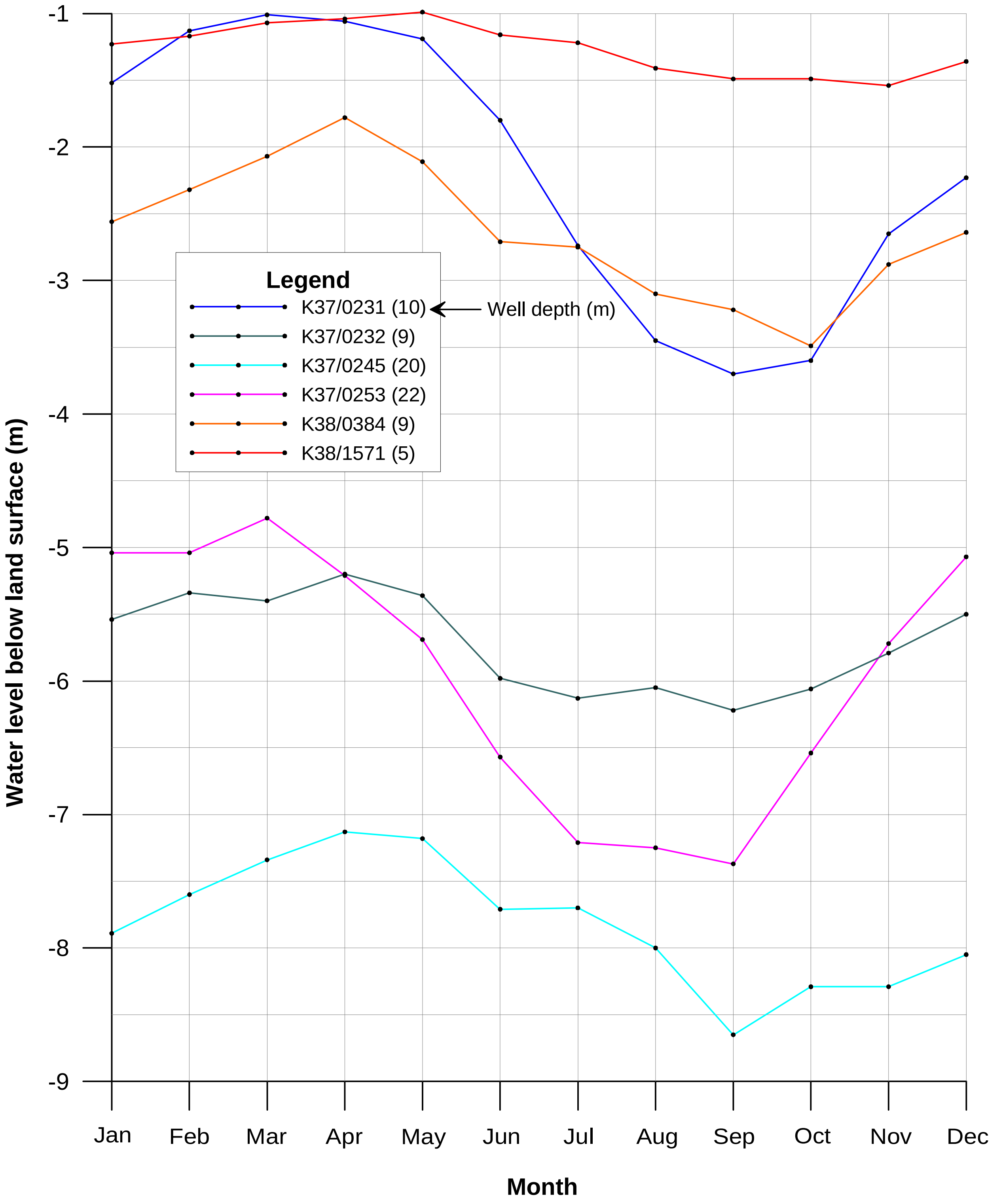

Figure 4.20 – Average monthly water level plots for selected wells within Zone 1.

The following paragraph relates to water level plots in Figure 4.6 showing the regional effects of Mayfield-Hinds Scheme recharge. Over summer, groundwater levels rose greatest near Carew (27 km inland), with smaller rises occurring with increasing distance up-gradient, north towards the Hinds River, coastward to approximately Emersons Rd (4 km inland) and down-gradient of Hinds Township, to approximately half way between Boundary and Surveyors Rd. The water level in wells K37/0666 (35 m deep) and K37/0261 (36 m deep) near Carew (27 km inland), rose 12.2 m and 12.0 m respectively over the irrigation season. At a similar distance inland but closer to the Hinds River wells K37/0444 (13 m deep) and K37/2162 (48 m deep) rose only 5 cm and 3.6 m respectively. With roughly equal amounts of border-dyke in both these two areas (refer to Figure 1.12 for the irrigated areas), the smaller rise nearer the Hinds River is either due to greater groundwater abstraction or some geological influence. Up-gradient of Carew (30 km inland), well K37/0374 (34 m deep) rose 4.2 m. Down-gradient of Carew near State-Highway 1, well K37/0245 (20 m deep) rose 4.0 m. 2.5 km up-gradient of Emersons Rd well K38/0384 (9m deep) rose 2.5 m and at Emersons Rd, well K38/1571 (5 m deep) rose 1.1 m. 1 km coastward of Emersons Rd in Zone 3, well K38/1892 (5 m deep) rose only 11 cm. Thus K38/1571 on the edge of Zone 1, roughly marks the boundary below which there is little or no recharge effect from the Mayfield-Hinds Scheme.

Recharge effects from the Mayfield-Hinds Scheme also dissipate rapidly from between the edge of the scheme and the Hinds River, downstream of Hinds Township. Well K37/0063 at Hinds Township rose 4.2 m. Well K37/2405 (10 m deep) 2 km down-gradient of the Township rose 2.8 m and well K37/0321 (9 m deep) at Boundary Rd, 3 km down-gradient of the Township rose 1.0 m.

From Boundary Rd upstream to Cracroft, water level data from wells K37/0268 (13 m deep), K37/0813 (40 m deep) and K37/0044 (19 m deep) adjacent to the Rangitata River showed no obvious river recharge effects, instead water level fluctuations suggest that Mayfield-Hinds Scheme recharge is dominant (Figure 4.21). Near Cracroft, the water level in well K37/0268 (400 m from the Rangitata River) was most affected by losses from the main race and rainfall recharge during winter 2006. Approximately 2 km downstream of the Hinds Arundel Bridge, the water level in well K37/0813 (900 m from the Rangitata River) dropped during winter 2005, this coincided with a period of low river flows and low rainfall. During the irrigation season the water level rose 6.6 m, before dropping 3.8 m over winter 2006, despite significant rainfall and a large flow event in late April occurring during this winter period. Water level fluctuations in

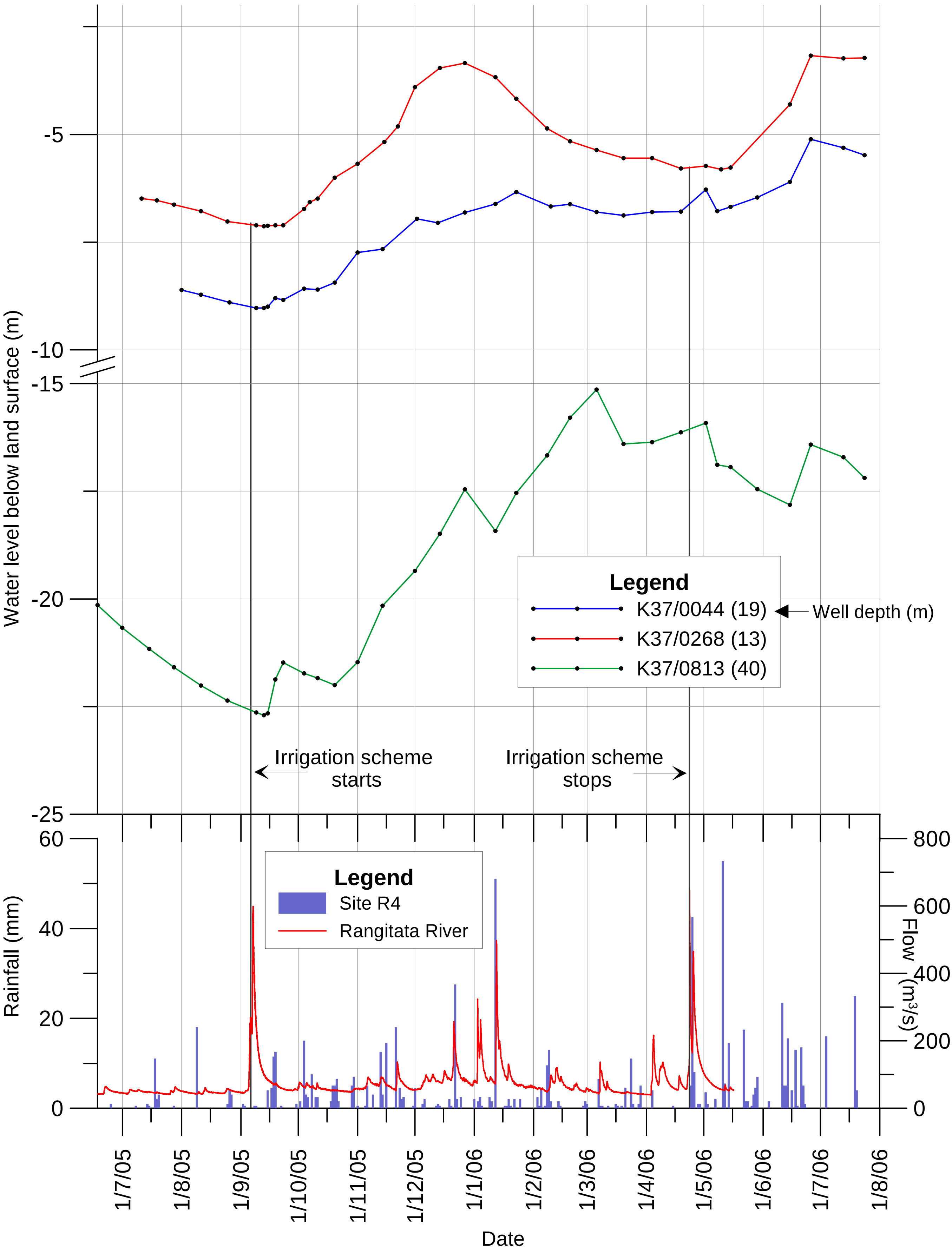

Figure 4.21 - Water level plots from wells in Zone 1, adjacent to the Rangitata River.

well K37/0044 (1.3 km from the Rangitata River) 4 km downstream of State-Highway showed a significant summer rise and similar overall water level pattern to other wells toward the center of the scheme.

Thus within Zone 1, water levels adjacent to the Rangitata River rise as a consequence of Mayfield-Hinds Scheme recharge. This rise in water level may reduce the quantity of water lost from the Rangitata River, or could reverse the flow of groundwater. Evidence for a reversal in flow from the Rangitata River, to flow into the Rangitata River is also provided in Section 4.4.3. In addition, this reversal is possibly evident by the water level fluctuations in well K37/0813, 900 m from the river. The water level in this well rose from 23 to 15 m below ground level over the course of the summer. At this location the Rangitata River is incised approximately 15 – 20 m into its fan (as taken from topographic contours). This suggests that for certain periods of time the adjacent groundwater level could either be lower than the surface of the river (river losing flow to groundwater) or higher than the surface of the river (river gaining flow from groundwater).

Zone 2

The following discussion relates to water level plots for wells K37/1563 – K37/2551 (48 – 67 m deep) in Zone 2, and well K370374 (34 m deep) in Zone 1 (Figure 4.22). Well K37/1563 was deepened to 67 m in January 2006. The deepened well is referred to as K37/2551. Because both wells shared the same water level, it is likely that the deeper well occurs within the same aquifer. The depth of wells K37/1563 – 2551 suggest that they could either occur in aquifers one or two. With no water levels taken during the drilling of well K37/1563, it is difficult to determine what aquifer these wells occur in. In contrast, well K37/0374 is only 34 m deep, and likely occurs in aquifer one. Wells K37/1563 – 2551 occur 1.6 km up-gradient of the Mayfield-Hinds Scheme, whilst well K37/0374 occurs 700 m within the scheme boundary, but 400 m up-gradient of the nearest border-dyke paddock.

In the absence of scheme recharge and below average rainfall, the water level in well K37/1563 dropped 9.0 m between May and October 2005. The rate of decline in well K37/1563 can be seen reducing with time. In late October 2005, the water level in well K37/0374 began rising and in early November 2005, the water level in well K37/1563 began rising. Both wells show a delayed scheme recharge effect. The recharge effect in well K37/1563 was most likely caused

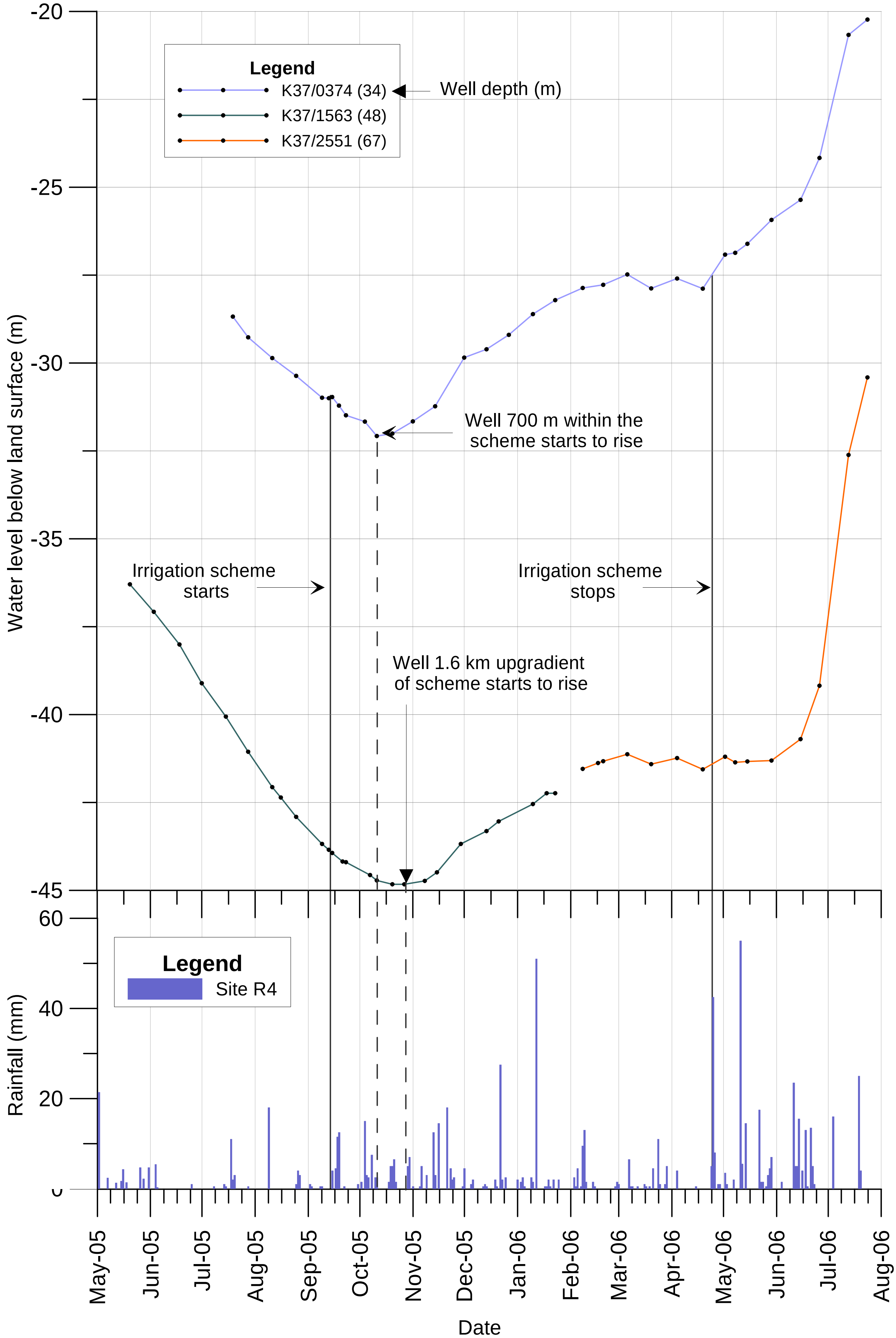

Figure 4.22 - Water level plots for selected wells monitored up-gradient of the Mayfield-Hinds Irrigation Scheme.

by a scheme recharge induced pressure wave propagating up-gradient. It is likely that this pressure wave also caused the water level rise in well K37/0374. However, in addition, the water level rise in well K37/0374 may have also been caused by losses from Irrigation Lateral 1, located up-gradient of the well. The time delay between the water level rises in each well, likely reflects the time taken for the pressure wave to move up-gradient. Between November 2005 and March 2006 the water level in well K37/1563 – 2551 rose 3.6 m and between October 2005 and March 2006 the water level in well K37/0374 rose 4.6 m.

The water level rise from well K37/1563 – 2551 shows that the scheme recharge extends to at least 1.6 km up-gradient of the scheme at this location. However it is not known whether this recharge effect occurs along the entire western edge of the scheme. The only other well with water level data at a similar distance up-gradient of the scheme is well K37/0271 (1.7 km up-gradient). In contrast to well K37/1563 – 2551, this well shows no evidence of a summer groundwater rise (refer to Section 4.3.3). This suggests a scheme recharge effect is only occurring at specific locations. Simultaneous water level readings taken from both wells may help to explain the differences, however the condition of well K37/0271 is such that water level readings can no longer be taken.

In response to significant rainfall over winter 2006, the water level in wells K37/1563 – 2551 and K37/0374 rose 11 m and 7.5 m respectively. These rises were at least double that caused by the scheme. This suggests that rainfall is the dominant source of recharge with a smaller but still significant contribution from the Mayfield-Hinds Scheme.

Zone 3 (Sub-Zones A and B)

The water level in well K38/1310 was highly affected by an area of local border-dyke irrigation (Figure 1.12), the water of which was sourced from Stormy Drain. The water level response to three border-dyke events is shown in Figure 4.12. The water level in this well rose 60 cm from September 2005 to January 2006 before declining to April 2006. This decline was caused by a combination of reduced rainfall and more severe water take restrictions on Stormy Drain. Thus it is highly likely that the groundwater within the two areas of drain water sourced border-dyke irrigation (red dashed Areas A and B, in Figure 4.1) rise approximately 50 cm each summer.

4.5.4 Local border-dyke recharge effects

Groundwater levels close to border-dyke paddocks (< 100 m away) show significant local recharge effects, with groundwater levels further away from border-dyke paddocks (> 300 m away) showing a smoother summer rise. Automated water level data from well K37/0232 showed no local border-dyke effect with the nearest border-dyke paddock 700 m cross-gradient (water level plot is shown in Figure 5.5). In contrast, wells K37/2527 (9 m deep) and K37/0442 (24 m deep) occur within a totally border-dyke irrigated farm. These wells showed a saw-tooth water level rise, with peaks (generally) related to the irrigation of specific border-dyke paddocks (Appendix 4.4 A). A record of the watering dates for each paddock over the majority of the 2005/06 irrigation season was provided by the farmer and selected paddocks (Appendix 4.4 B) were compared to groundwater levels in each well. Results show that well K37/0442 was most affected by paddock 1, 140 m up-gradient of the well and possibly to a lesser extend by paddock 2 also up-gradient. Irrigation from paddock 1 produced an average water level rise of 1 m. Though manual readings taken at (approximately) 2 weekly intervals did not provide an exact time of how long water levels took to rise following the irrigation of this paddock, readings taken on the day that paddock 1 was irrigated and then 5 days later show that irrigation recharge occurs within at least 5 days. Paddock 9, 20 m cross-gradient from the well and paddocks 18 and 19, approximately 150 m down-gradient of the well all showed no border-dyke effect. Near the end of February 2006, an automated water level recorder was placed down well K37/2527. Automated water level readings show that paddock 56 (up-gradient of the well) has the biggest effect, with the level rising within one day of irrigating. In most cases a group of paddocks close this well were irrigated within a few days of each other. The combined recharge effect from irrigating multiple paddocks was an approximately 1 m rise in the groundwater level.

The most distinct local border-dyke effect was recorded in well K38/0385 (8 m deep) located within a wide laser-leveled border-strip near the coastward edge of the scheme (Figure 4.1). Automated water level readings show four sharp peaks prior to the 1st of April (Figure 4.7). These were caused by irrigation of the border strip with the remaining peaks caused by rainfall. Figure 4.23 shows the watering dates and times for Border Irrigation Event A, and the subsequent water level fluctuations in the well. The location of the paddocks irrigated is shown in Appendix 4.5.

Irrigation of paddock NE, down-gradient of the well, had no effect on the water level in well K38/0385. Coinciding with the irrigation of the slightly up-gradient paddock NG, the water

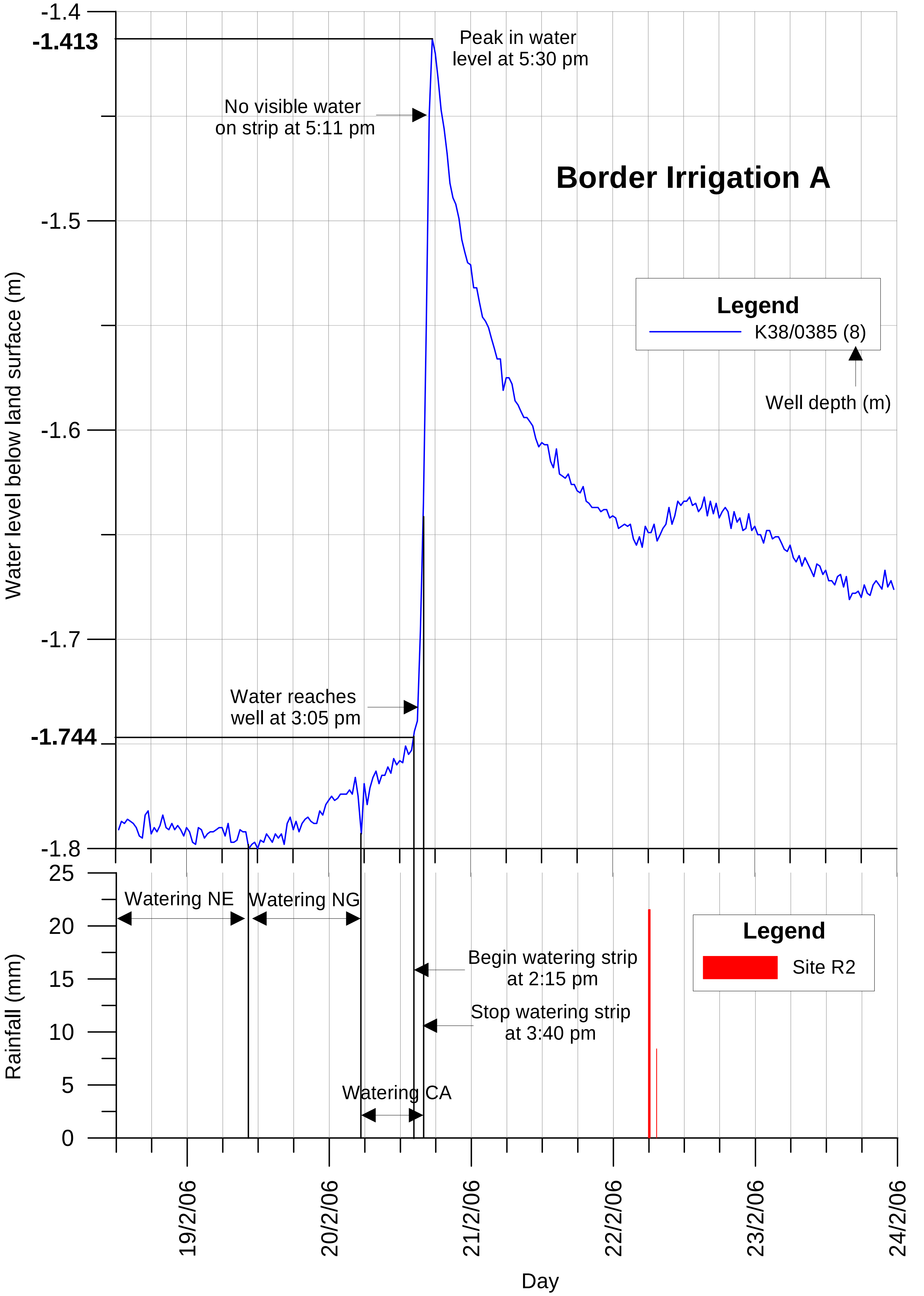

Figure 4.23 - Water level response in well K38/0385 to border-dyke irrigation.

level in the well rose approximately 30 cm. This rise continued during the irrigation of paddock CA. Irrigation of paddock CA starts at the Isleworth Rd end of the paddock and finishes with the last border-strip where the well is located. Irrigation of adjacent strips within this paddock had relatively little effect in comparison to the water level rise which occurred when watering the final border strip. The water level started rising sharply from 2:15 pm, the exact time that water was first applied to the border strip. However the immediate rise may be due to a delayed recharge effect from the adjacent border strip which had just finished watering. 50 min was taken for the watering front to reach the well (located 140 m down from the headrace) and water was observed bubbling down through the soil as it moved down the strip. No water could get in through the top of the well casing and a concrete pad around the well head should have prevented water infiltration down the side of the casing. Watering ceased at 3:40 pm and by 5:11 pm no surface water was visible on the strip. The water level peak occurred at 5:30 pm, with an overall rise of 33 cm, 3 ½ hours after watering water began. The initial water level drop was rapid, but reduced over time with an overall decline of 23 cm over 1 and ½ days. Over the following 6 days, the water level dropped by another 9 cm, after which time groundwater levels started to rise again. This overall rise was likely caused by scheme recharge further inland.

4.5.5 Local spray irrigation recharge effects

Spray irrigation is unlikely to cause a significant local rise in groundwater levels. This is because a greater percentage of the water applied under this method of irrigation is stored within the soil profile. Well K3/0232 (9 m deep) is located within a paddock irrigated using a soft hose gun. These are high pressure irrigators mounted on a trolley, and are self propelled using a winch used to pull the gun towards the other end of the paddock. Typical application depths range from 50 – 70 mm.

During an irrigation event the gun applies water immediately adjacent to the well. Irrigation on the 18/1/06 had no observable effect on the water level (Appendix 4.6). Another example is well K37/0374 (34 m deep), located 50 m away from the irrigation path of a centre pivot. This centre pivot applies between 5 and 15 mm per application. From 2 weekly manual readings and a record of irrigation dates, no local water level rises could be attributed to the irrigation water applied from this pivot.

It is likely that most local spray irrigation recharge effects are not observed in water level measurements, because the border-dyke recharge effects are dominant. However spray irrigation from the Mayfield-Hinds Scheme will be contributing to the overall regional rise in summer groundwater levels. Evidence for this comes from the Waimakariri Irrigation scheme. Prior to 1991, groundwater levels within the scheme were lowest in summer and highest in winter. However, since 1991 when the scheme commenced, groundwater levels have been similar throughout the year (shown by well M35/0312). In addition, soil moisture levels under spray irrigated paddocks are generally maintained at a higher level, thus drainage from the soil profile after a rainfall event is likely to be greater than that occurring under dryland conditions.

4.6 Tidal Effects

Mean tide height data from the Rangitata River Mouth (NIWA, 2006) was compared to the tidal fluctuations in well K38/1310 (8 m deep) in un-confined aquifer one, 120 m inland from the coast, and well K38/1806 (76 m deep) in aquifer two, 2.0 km inland from the coast (Figure 4.24). Tidal effects on aquifer two are discussed in Chapter 6.3. An approximately 2 hour time delay occurred between high tide and the water level rise in well K38/1310. The tidal water level fluctuation was 5 – 7 cm, with larger tidal fluctuations causing larger water level fluctuations (Figure 4.24). This tidal water level fluctuation was caused by loading which reduces the pore volume and expels water from within the aquifer (McWhorter and Sunada, 1977). For a given load, the water level rise in the unconfined aquifer is smaller than a confined aquifer because the groundwater is free to move upward and therefore can not support as large a load (McWhorter and Sunada, 1977).

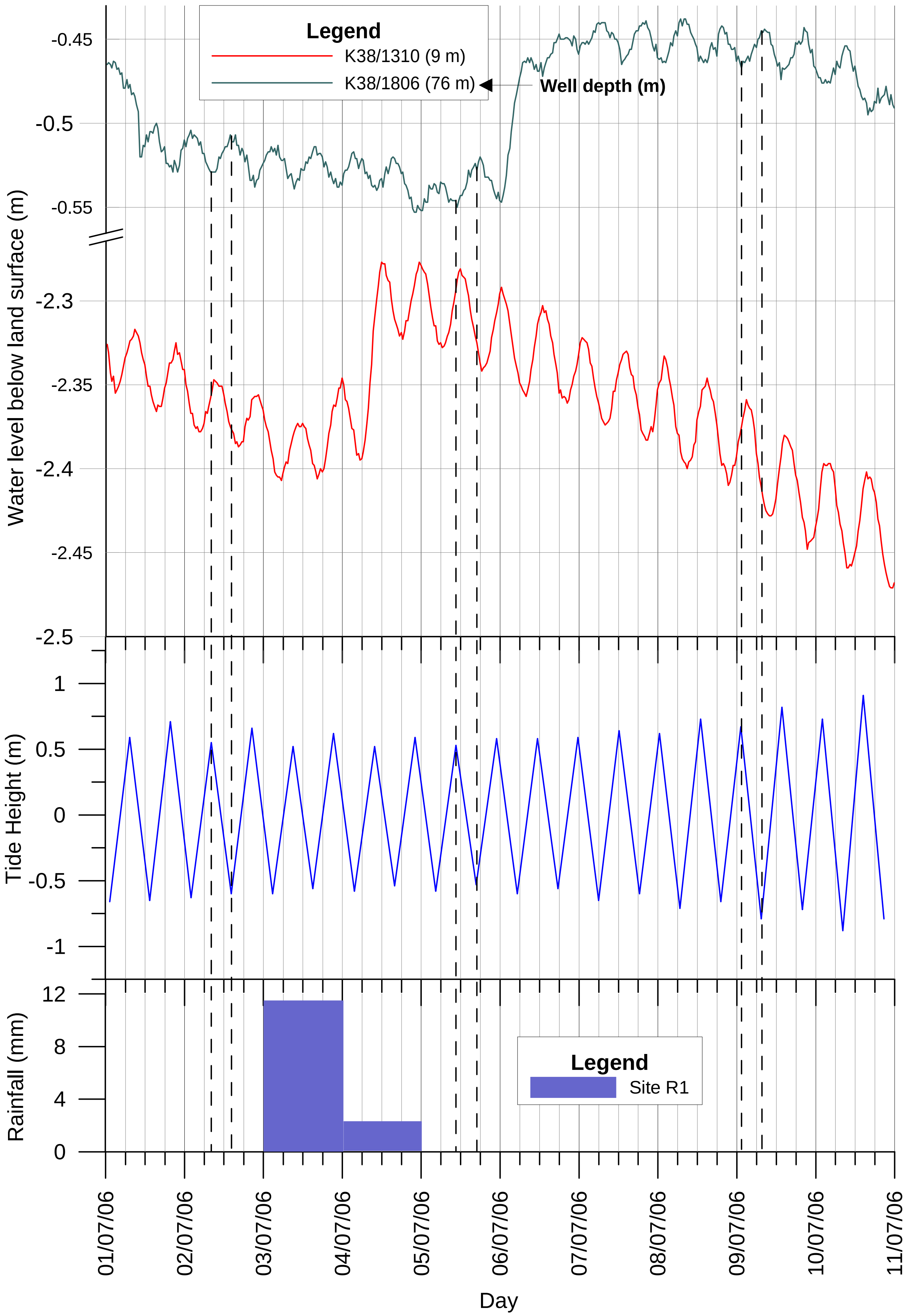

Figure 4.24 – Tidal water level response in aquifers one and two.

4.7 Groundwater Discharge

4.7.1 Groundwater abstraction

Regional effects

The affects of groundwater abstraction on groundwater levels were not observable on a regional scale. Over summer, water levels in Zones 1 and 2 rose despite significant groundwater abstraction, showing that scheme recharge was significantly greater than the discharge from groundwater abstraction. It is likely that summer groundwater levels within Zones 1 and 2 would rise more in the absence of groundwater abstraction. However, the extent to which this would occur is difficult to estimate, especially within the higher water table areas where seasonal groundwater fluctuations are small. In Zones 3 – 7, the main reason why no groundwater abstraction effects were observed was related to a lack of groundwater abstraction from aquifer one. In Zones 3 and 4, this was largely caused by a readily available supply of surface water which is used as an alternative to groundwater sourced irrigation. In addition, low summer rainfall meant that groundwater levels would have dropped in Zones 3 and 5 (both of which are dominantly rainfall recharged) anyway. In Zones 4, 6 and 7, any abstraction effects could not be distinguished because river and rainfall recharge effects were more dominant.

Local effects

As a result of two factors, no local pumping effects were observed from aquifer one. Firstly water level measurements were taken from wells generally 1 km away or further from the nearest first aquifer irrigation well in order to determine the regional groundwater patterns. As a result, any pumping effects were so small that they could not be recognized. Secondly, groundwater within aquifer one preferentially flows through numerous discrete, laterally and vertically discontinuous gravel lenses separated by less permeable claybound and silty gravel. Thus it is likely that this mode of groundwater occurrence would make it difficult to predict the pumping effects on neighboring wells. Wells tapping the same permeable lenses may induce large local effects, whilst wells tapping separate lenses may have little or no effect. This hypothesis is vividly demonstrated from automated water level readings from well K38/0385 (8 m deep) which showed no effects from the pumping of irrigation gallery K37/2250 (10 m deep), 300 m across gradient.

4.7.2 Spring discharges

The reasons why groundwater levels rise more inland in response to both rainfall and Mayfield-Hinds Scheme recharge is largely due to a combination of greater border-dyke irrigation east of State-Highway 1, a greater annual rainfall further inland, and the progressive reduction in groundwater discharge with increasing distance inland from the coast. This reduction in groundwater discharge is caused by a deepening of the water table with increasing distance inland from the coast. For example the water level in aquifer one is approximately 35 – 20 m below ground level inland near Carew, as opposed to between 8 and 1 m below ground level nearer the coast. This means that further inland, groundwater discharges are reduced because it is unlikely that the water table (in many locations) will intercept the land surface. As a result the water table rises more because the aquifer further inland is storing a greater percentage of the recharge water.

The higher water table and consequently smaller water storing capacity of aquifer one, within Zones 3, 4 and parts of Zone 1, means that water table rises in response to rainfall, river or scheme recharge cause significant groundwater discharges out of the aquifer via springs and drains. As the water table rises further, a larger percentage of the water table intercepts the land surface. This progressively increases the amount of groundwater discharged from the aquifer until the aquifer reaches a point where even a significant quantity of recharge only causes a very small rise in groundwater levels. Therefore a small water level rise of 50 cm at the coast, may cause significant spring flows, drain flows and potential drainage problems. These concepts are demonstrated by the relationship between groundwater level fluctuations and drain flows, discussed in Chapter 6. Hence the smaller water table rise near the coastward end of the Zone 1 and adjacent to the Hinds River within Zone 1, in no way suggests that scheme has a lesser impact on the groundwater system. In contrast, the scheme water not stored within the aquifer is having a significant impact on the springs and drains within or that pass through the Zone 1.

4.8 Zone Summary

4.8.1 Zone 1

Within Zone 1, the Mayfield-Hinds Irrigation Scheme is the dominant source of recharge. Thus, since 1982 when the majority of the scheme was being irrigated, groundwater levels have been highest from March to April and lowest from September to October. Early on in the irrigation season, water levels also rise from race losses to groundwater. The water level rise over summer is highest near Carew (10 – 12 m) and reduces with increasing distance up-gradient, north towards the Hinds River, coastward to approximately Emersons Rd and down-gradient of Hinds Township (approximately half way between Boundary and Surveyors Rd). The rise in water levels increases the flow in springs which occur near the lower end of the scheme (Chapter 6.3.11). Spring flow is highest after significant summer scheme recharge followed by heavy winter rainfall, or heavy winter rainfall followed by significant summer scheme recharge.

Though the effects of rainfall recharge are not obvious from monthly groundwater readings (i.e. groundwater levels generally show a consistent summer high and winter low each year), winter rainfall does have a significant effect on the overall long-term upward and downward trend.

4.8.2 Zone 2

Rainfall is the dominant source of recharge with less but still significant scheme recharge (pressure induced effects) occurring at specific locations. During the course of this study, the water level in wells K37/1563 (48 m deep) and K37/2551 (67 m deep), rose 3 – 4 m in response to scheme recharge (both 1.6 km up-gradient of the scheme). This groundwater level rise was likely caused by a pressure effect propagating up-gradient of the scheme. In contrast, historic water level data from well K37/0271 (30 m deep), 1.7 km up-gradient of the scheme shows a strong correlation to rainfall with no evidence of scheme recharge. It is not known why a scheme induced recharge only occurs in some wells.

4.8.3 Zone 3

Rainfall is the dominant source of recharge and groundwater level fluctuations are smallest in this Zone. Seasonal groundwater level fluctuations are smaller because of the high water table (less than 2 m) and the large number of springs and drains. Water levels do not rise significantly because these springs and drains discharge progressively more quantities of water from the aquifer as the groundwater level rises. 300 m inland from the coast, tidal water level fluctuations of between 5 and 7 cm occur, with larger tidal fluctuations causing larger groundwater level fluctuations.

The groundwater level is generally highest from May to June and lowest in December. In contrast to Zone 1, groundwater levels decline by 10 – 20 cm between July and December and rise 10 – 20 cm from January to June. Two reasons are likely reasons why groundwater levels in Zone 3 are highest in winter. First, the higher winter water levels result from a delayed recharge effect from the Mayfield-Hinds Scheme. Second, the higher winter water levels result from rainfall exceeding evapotranspiration during winter. Groundwater levels collected over the course of this study strongly showed a rainfall recharge influence with no discernable effect from the Mayfield-Hinds Scheme. Thus the high water level in winter is likely caused by rainfall. The exception to this pattern of seasonal fluctuations occurs within drain sourced border-dyke areas. Here groundwater levels rise approximately 50 cm each summer.

4.8.4 Zone 4

The Hinds River is the dominant source or recharge to aquifer one with a smaller but still significant contribution from rainfall. Water levels were highly affected Hinds River flow and rainfall, with no direct recharge effect from the Mayfield-Hinds Scheme. Indirectly the scheme may cause water levels (adjacent to the Hinds River) to rise by increasing the flow in drains (dominantly from the Northern Drain) which then flow into the Hinds River (refer to Chapter 6.5). During low flow in the Hinds River, the water table slopes in towards the river. During high flows the water table slopes away from the river suggesting a change in groundwater flow direction during times of alternating high and low river flows. Near Surveyors Rd, the effects of Hinds River recharge extend no further than 600 m distance away from the river.

4.8.5 Zone 5

Aquifers one and two are dominantly rainfall recharged, with the boundary between dominantly rainfall and dominantly Hinds River recharged groundwater, extending 1.5 km distance out from the Hinds River. Towards the centre of the Rangitata fan, away from the Hinds River, groundwater level fluctuations are likely to be larger than in any other area on the Hinds Rangitata Plain. Rainfall events have the potential to cause the greatest groundwater level rise any where on the Hinds Rangitata Plain. Water level rises of between 12 and 16 m occur in response rainfall months exceeding 150 mm. These 12 – 16 m rises may occur within 1 – 2 months of a large rainfall event, with water levels dropping rapidly soon after they peak.

4.8.6 Zone 6

Water level fluctuations in aquifer one show subtle recharge effects from the Rangitata River and little or no response to Mayfield-Hinds Scheme recharge. Significant water level rises with rainfall and the general coinciding of rainfall with peak river flow suggest that rainfall and river losses are the dominant sources of recharge.

4.8.7 Zone 7

Losses to groundwater from the Hinds River account for the majority of groundwater recharge to aquifer one from Mayfield Township to 14 km downstream. River recharge extends 1.5 km away from the Hinds River. With increasing distance away from the river, the groundwater level rise in response to higher river flows is reduced in magnitude and delayed in time. Following a large flow event, the water level in well K37/0381 rose for at least 3.5 km downstream of where the Hinds River stopped flowing. This suggests a wave of water propagating downstream in front of the surface flow. Where this wave of water intercepted the land surface springs within the bed of the river started flowing.

4.9 Regional Groundwater Fluctuations, Changes with Time

4.9.1 Water level fluctuations

Figure 4.25 shows changes in groundwater levels within aquifer one over four time periods. Data was gathered from 50 wells monitored during the course of this study. The first three periods cover 74 days each, and show the change in groundwater levels in response to rainfall, scheme recharge and the Hinds and Rangitata Rivers from the September 2005 to April 2006. The last period covers 68 days and shows the changes in water levels as a consequence of heavy winter rainfall, increased flow in the Hinds and Rangitata Rivers and no surface water irrigation.

An estimate of rainfall, water use by the Mayfield-Hinds Scheme and of groundwater abstraction, based on the depths (mm) of water applied from two centre pivots, were made to help explain the changes in water levels at each time period (Appendix 4.7). These variables were also totaled for a 74 day period prior to the first time period, thus providing information to predict why water levels would have changed in time period 1.

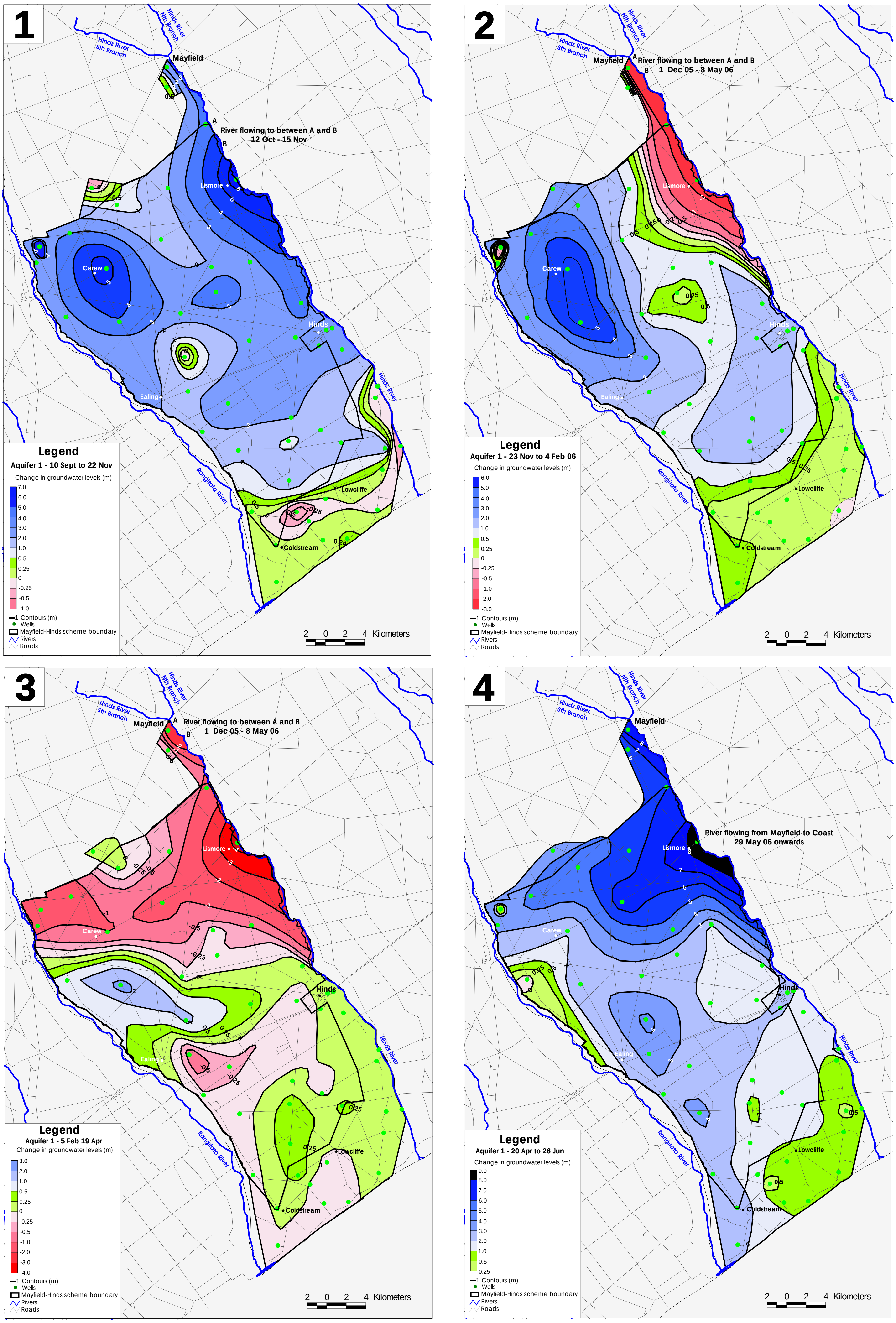

Figure 4.25 - Seasonal changes in groundwater levels for aquifer one.

Period 1) During the first third of the irrigation season water levels rose highest near Carew and adjacent to the Hinds River near Lismore. This rise near Carew occurred from scheme recharge, and the rise adjacent to the Hinds River resulted from increased river flow. The small rise in water levels coastward of the Mayfield-Hinds Scheme in Zone 3 was likely the result of increased rainfall rather than Mayfield-Hinds Scheme recharge (shown in Appendix 4.7). Period 2) Groundwater levels continued to rise most rapidly near Carew, in contrast water levels adjacent to the Hinds River declined, suggesting that recharge from the Hinds River may extend 3 – 4 km from the river. An increase in water levels up-gradient of the scheme and in an area between the irrigation scheme and the Emersons Rd suggests delayed scheme recharge. The continued water level rise closer to the coast was likely caused by an additional 30 mm of rainfall during this period, as recorded at Site L1. Period 3) Groundwater levels decline over much of the scheme area, especially in the north eastern corner of the scheme. The overall decline in groundwater levels was likely caused by a combination of less rainfall, low flow in the Hinds River and to a lesser extent, water take restrictions on the Mayfield-Hinds Scheme. Period 4) During this period rainfall caused a significantly greater water level rise in Zones 2, 3, 4 and 5 in comparison to the rises in response prior recharge events. The exception was near Carew where water levels dropped, likely in response to the absence of scheme recharge. The greatest water level rise occurred close to the Hinds River (near Lismore) in response to increased river flow.

4.9.2 Depth to groundwater

Figure 4.26 shows changes in the depth to groundwater contours for aquifer one at four separate dates. For dates 1, 2 and 4 water levels were taken from 50 wells monitored during the course of this study. For date 3, water levels were taken from 76 wells used in the May 2006 piezometric survey. The first date shows the pre-irrigation season contours, the second shows the post-irrigation contours, the third shows the effects of rainfall during winter 2006 and the fourth shows the effects of extra winter (2006) rainfall and increased flow in the Hinds River.

Date 1) At the beginning of the irrigation season, groundwater levels where highest within Zone 3. Depth to groundwater increased inland and towards the Rangitata River. Date 2) At the end of the irrigation season, groundwater contours showed a marked change in orientation. Near the top of the scheme, depth to groundwater contours are more parallel to the coast, with an increase in water levels inland rather than increasing towards the Rangitata River. This was caused by the

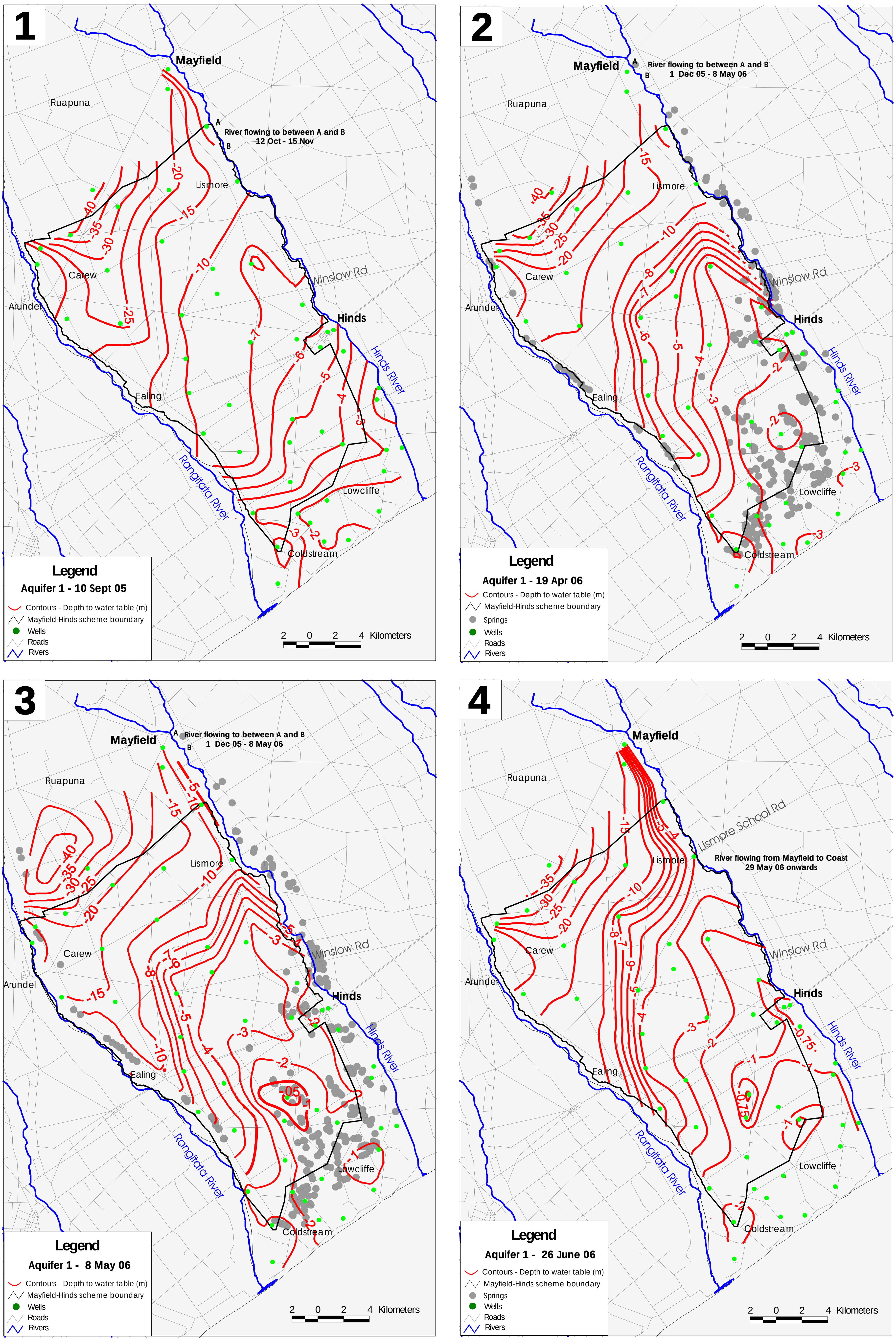

Figure 4.26 - Seasonal changes in the depth to groundwater for aquifer one.

greater water level rise near Carew, relative to the rise in water levels closer to the Hinds River. Near the middle of the scheme, depth to groundwater increased more rapidly across the plains and towards the Rangitata River. This was caused by a greater water level rise within the area east of the – 3 m contour line and inland of Zone 3. Note the considerable groundwater level rise near Hinds Township. This caused a groundwater-fed flow from springs within the bed of the Hinds River (refer to Chapter 6.5) upstream of Winslow Rd. Date 3) Within 20 days following the cessation of irrigation, approximately 70 mm of rain fell, including a 50 mm rainfall event. This caused a considerable increase in drain flows due in part to increased spring flow, and the activation of dry springs where the groundwater intercepted the land surface. It is highly likely that spring flow would have been less and in some cases non-existent without the prior rise in groundwater levels induced by the Mayfield-Hinds Scheme. Springs located between the -2 m contour line and the northern edge of Zone 1 (shown in Date 2) likely occur in an area most affected by the combination of Mayfield-Hinds Scheme and rainfall recharge. Step 4) Over a period of 50 days from Date 3 to Date 4, 180 – 200 mm of rain fell. The rainfall caused significant water level rises over the entire area including the area near Carew. In addition the Hinds River now flowed for its entire length from Mayfield Township to the coast. This caused the water table to rise adjacent to the river over its entire length, the largest rises occurring between approximately Winslow Rd and Lismore School Rd where the river was previously dry.

4.9.3 Groundwater flow direction

Figure 4.27 shows changes in the groundwater flow direction within aquifer one at four separate dates. Data was gathered from 50 wells monitored during the course of this study. The first date shows the post-irrigation flow direction, the next two shows the flow direction half way through and at the end of the irrigation season, and the last date shows the flow direction after heavy rainfall and increased flow in the Hinds River.

In general the flow contours moved coastward in response to rising groundwater levels over both the irrigation season and winter periods. As a consequence of smaller water level fluctuations no major changes in groundwater flow direction occurred coastward of the 120 m contour line. In contrast, flow direction inland of the 120 m contour line was significantly altered by the scheme, rainfall and Hinds River recharge. Winter (2006) rainfall had the greatest effect inland of the 160 m contour line, causing a large shift down-gradient. The Mayfield-Hinds Scheme had the greatest effect on the 180, 160 and 140 m contour lines within and down-gradient of Carew.

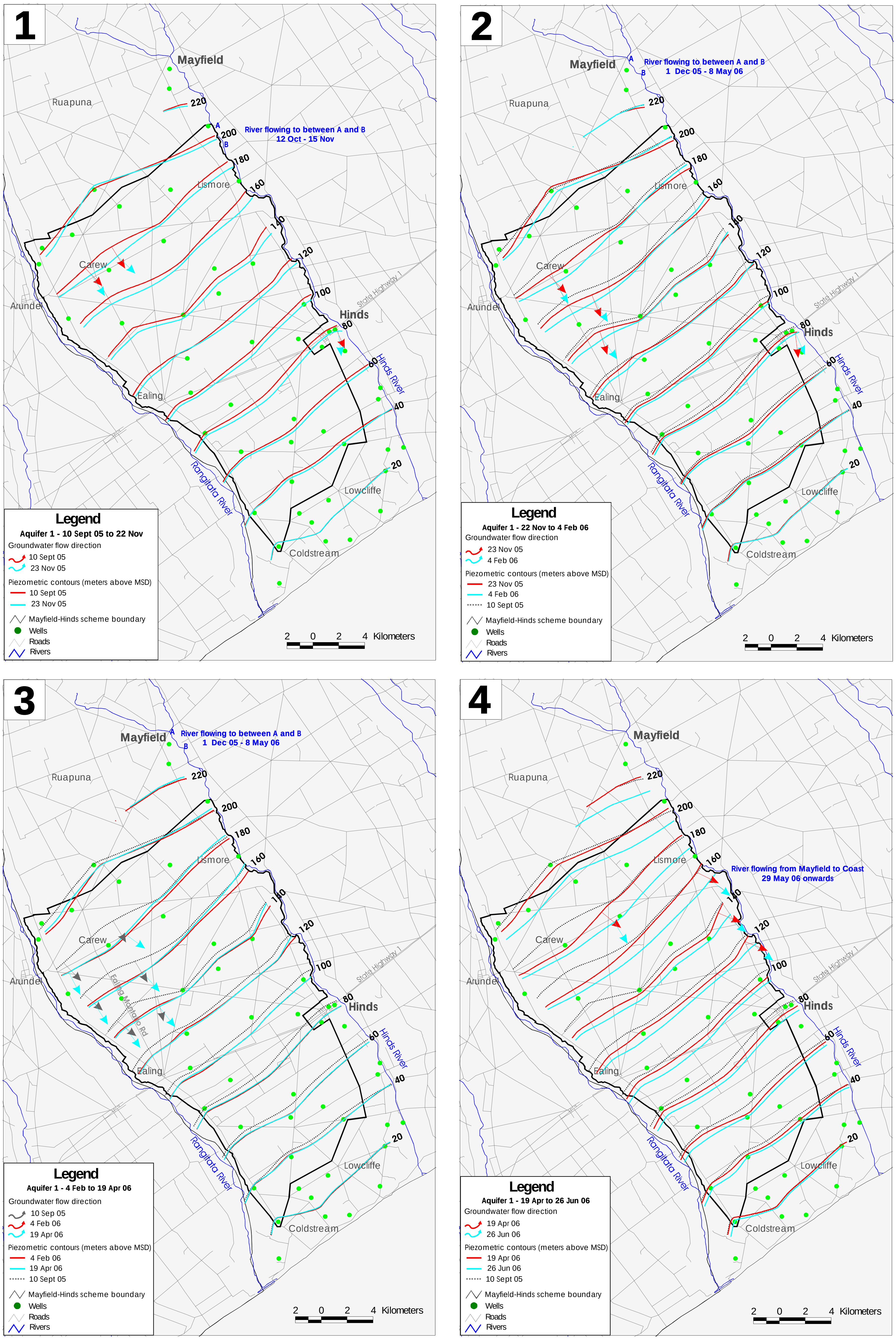

Figure 4.27 - Seasonal changes in groundwater flow direction levels for aquifer one.

This is shown by the blue and grey flow arrows in Figure 4.16 (Date 3). At the beginning of the irrigation season both these contours suggested groundwater flowing from the Rangitata River and groundwater flowing towards the Rangitata River, both converging at approximately Ealing Montalto Rd. By the end of the irrigation season this was reversed with flow diverging out either side of Ealing Montalto Rd. This was likely caused by groundwater mounding near Carew. In terms of river losses this suggests that the upper section of the Rangitata River may lose water during periods of low groundwater levels and may lose less water or gain water when adjacent groundwater levels are high. Another effect of the scheme was shown in Date 1 with the blue 80 m contour line (near Hinds Township) showing significantly more groundwater flow out from the Hinds River. This was caused by the frequent large bywash releases from Irrigation Lateral 3 during October 2005. Alternating high and low flows in the Hinds River caused significant contour movement (upstream of the 120 m contour line) upstream and downstream during non-flowing and flowing periods. An effect from all recharge sources was an increased hydraulic gradient (from the 20 – 200 m contour lines) from 6.4 m/km at the start of the irrigation season, 6.6 m/km at the end of the irrigation season and 6.9 m/km at June 2006. At a more local scale the increase in hydraulic gradient was greatest inland from the 120 m contour line where the rise in groundwater levels was greatest. In contrast there was very little change in hydraulic gradient near the coast between the 20 and 40 m contour lines.

4.10 Implications for Water Management

An important conclusion gained from this study is that the Mayfield-Hinds Scheme provides a significant proportion of recharge to aquifer one within the Hinds Rangitata Plain. The overall footprint (area of groundwater receiving scheme recharge) of the scheme is likely restricted to Zone 1, and Zone 2 to a lesser extent. However, increased irrigation efficiency and a progressive change from border-dyke to spray within the scheme, will ultimately reduce the amount of scheme recharge and subsequent flow from spring fed drains which occur with Zone 1. If the scheme were to switch totally to spray irrigation, it is likely that average groundwater level in aquifer one would drop by approximately 0.5 m near the coastward edge of Zone 1. With increasing distance inland, the average groundwater level would progressive drop by up too 10 m near Carew. As a result of lower average groundwater levels, many first aquifer wells will go dry more frequently and for longer periods of time. The worst effected people would be those who irrigate from galleries, many of which are less than 10 m deep. In addition, a significant number of landowners who irrigate from drains, may be forced to look for an alternative source of irrigation water as the reliability of supply from spring fed drains which rise in response to scheme recharge will reduce.

When drilling a new well in Zones 2 and 5, it is important to take into account the large fluctuations in groundwater levels. Groundwater fluctuations of at least 20 m occur within aquifer one. Thus wells drilled during periods when groundwater levels are high, should allow for at least at least 30 m of drawdown.

Within Zone 3, water level fluctuations are relatively small and both groundwater levels and drain flows are more dependent on local rainfall. Wells within this Zone are unlikely to go dry, even during long periods of low rainfall. However, drain and spring flows are highly sensitive to even small fluctuations in the water table, and as such, the surface water resource within Zone 3 is far more variable than the groundwater.

4.11 Summary and conclusions

Analysis of water level data shows that aquifer one within the Hinds Rangitata Plain can be divided into seven distinct zones based on differences in the dominant source (s) of groundwater recharge within each zone. A summary of the groundwater recharge source (s), in order from greatest to least dominant, is provided (below) for each Zone:

- Zone 1 – Mayfield-Hinds Irrigation Scheme, Rainfall, Hinds River
- Zone 2 – Rainfall, Mayfield-Hinds Irrigation Scheme
- Zone 3 – Rainfall
- Zone 4 – Hinds River, Rainfall
- Zone 5 – Rainfall
- Zone 6 – Rainfall, Rangitata River
- Zone 7 – Hinds River, Rainfall

In general, seasonal groundwater fluctuations increase with increased distance inland from the coast. As a consequence, groundwater levels further inland rise more in response to recharge from rainfall, river or the Mayfield-Hinds Scheme. A larger seasonal fluctuation is the main reason why groundwater flow direction is most changeable at greater distances inland from the coast. A scheme recharge induced pressure affect also caused the water level to rise at one location 1.6 km up-gradient of the scheme.

Groundwater discharge from springs is highly affected by groundwater levels, with greater discharges occurring when water levels are high. Within Zone 1, spring fed drain flows are dependent upon a combination of scheme and rainfall recharge, in contrast Zone 3, which dominantly dependent on rainfall alone. In terms of water management, it is important that the effects of future reductions in scheme recharge are taken into account when allocating both the groundwater and surface water resources.

Chapter Five

Groundwater Level Fluctuations in Aquifers Two and Three

5.1 Introduction

Water levels in aquifers two and three, and the recharge and discharge components of the groundwater system were monitored simultaneously over much of the Hinds Rangitata Plain. This information enabled an assessment of the sources of recharge, and the short-term water level responses. Aquifers two and three are the same as those identified in Chapter 3. Prior to this study, little or no previous work on the groundwater responses of aquifers two and three had been carried out. As such, there is no long-term data for either of the two deep aquifers.

Research findings were used to determine:

- The effects of rainfall and the Mayfield-Hinds Irrigation Scheme, both spatially and with depth.
- The difference in water level fluctuations between Hydrogeological Section 4A and the remaining area within groundwater recharge Zone 1.
- The water level response to local border-dyke irrigation and rainfall recharge events.
- The tidal effects in aquifer two near the coast.

The methodology (refer to Chapter 4.2) and groundwater recharge zones (refer to Chapter 4.1.2) used in this chapter, are the same as those used for aquifer one, described in Chapter 4.

5.2 Methodology

Two weekly water level measurements were taken from six second aquifer wells and two third aquifer wells over the course of this study (Table 5.1). Unlike aquifer one, the majority of second and third aquifer wells were used for irrigation, thus very few deeper wells were available for water level monitoring. As consequence, water levels measurements were taken from fewer second and third aquifer wells.

Table 5.1 – Second and third aquifer wells monitored during the study.

<table>
<tr><th>Aquifer</th><th>Well</th><th>Depth (m)</th><th>Zone</th></tr>
<tr><td rowspan="6">2</td><td>K37/1685</td><td>83</td><td rowspan="4">1</td></tr>
<tr><td>K37/1714</td><td>57</td></tr>
<tr><td>K37/1999</td><td>62</td></tr>
<tr><td>K37/2183</td><td>110</td></tr>
<tr><td>K38/1806</td><td>76</td><td>3</td></tr>
<tr><td>K37/1519</td><td>89</td><td>5</td></tr>
<tr><td rowspan="2">3</td><td>K37/1773</td><td>132</td><td rowspan="2">1</td></tr>
<tr><td>K37/2417</td><td>76</td></tr>
</table>

The location and details of the eight second and third aquifer wells, and the boundaries for each groundwater recharge zone is provided in Figure 5.1 in the text, and Figure 5.1 in the back pocket. Water level plots for the six second aquifer wells and two third aquifer wells are provided in Figures 5.2 and 5.3 respectively.

5.3 Rainfall Responses

5.3.1 Rainfall during the study

During this study, record low rainfall occurred during winter 2005 and over the 2005/06 irrigation season. In contrast, record high rainfall occurred during winter 2006. Between April and mid September 2005 the total winter rainfall at Site L5 was 98 mm less than the mean total rainfall over this period, and the sixth lowest total in 41 years. Between April 2005 and March 2006, the total rainfall at Site L5 (25 km inland) was 230 mm less than the mean total rainfall over this period, and the second lowest total in 41 years. Rainfall Site L1 (2 km inland) was 209 mm below the mean, the second lowest total in 41 years. In contrast, between May and the end of August 2006, the total rainfall at Site L5 was 111 more than the mean total rainfall over this period and the fourth highest total in 41 years. Rainfall Site L1 was 108 mm above the mean, the third highest total in 41 years. Thus winter 2006 was one of the wettest on record.

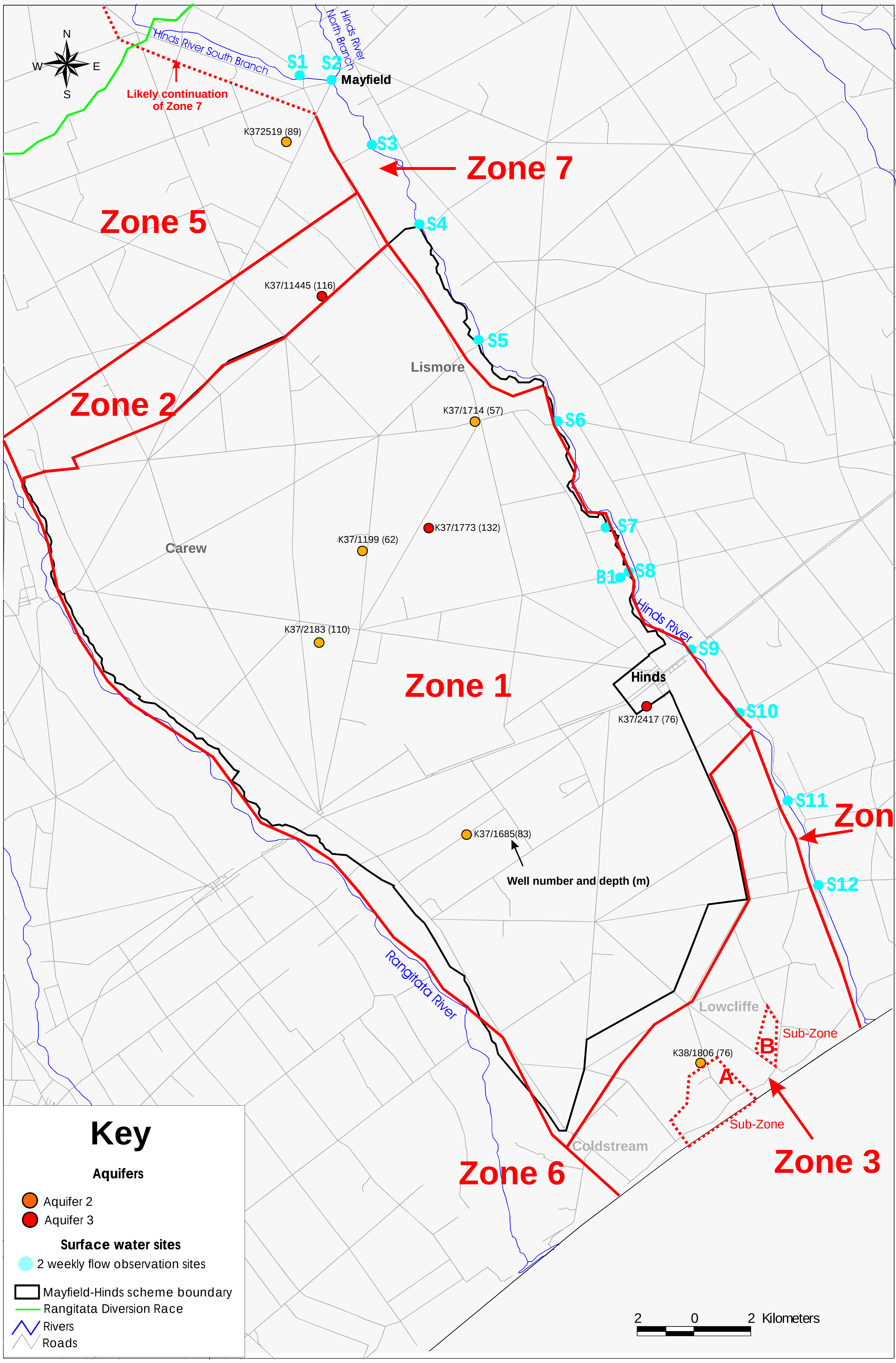

Figure 5.1 - Map showing the dominant recharge zones, the location and details of wells discussed in Chapters 5, and the Hinds River flow observation sites.

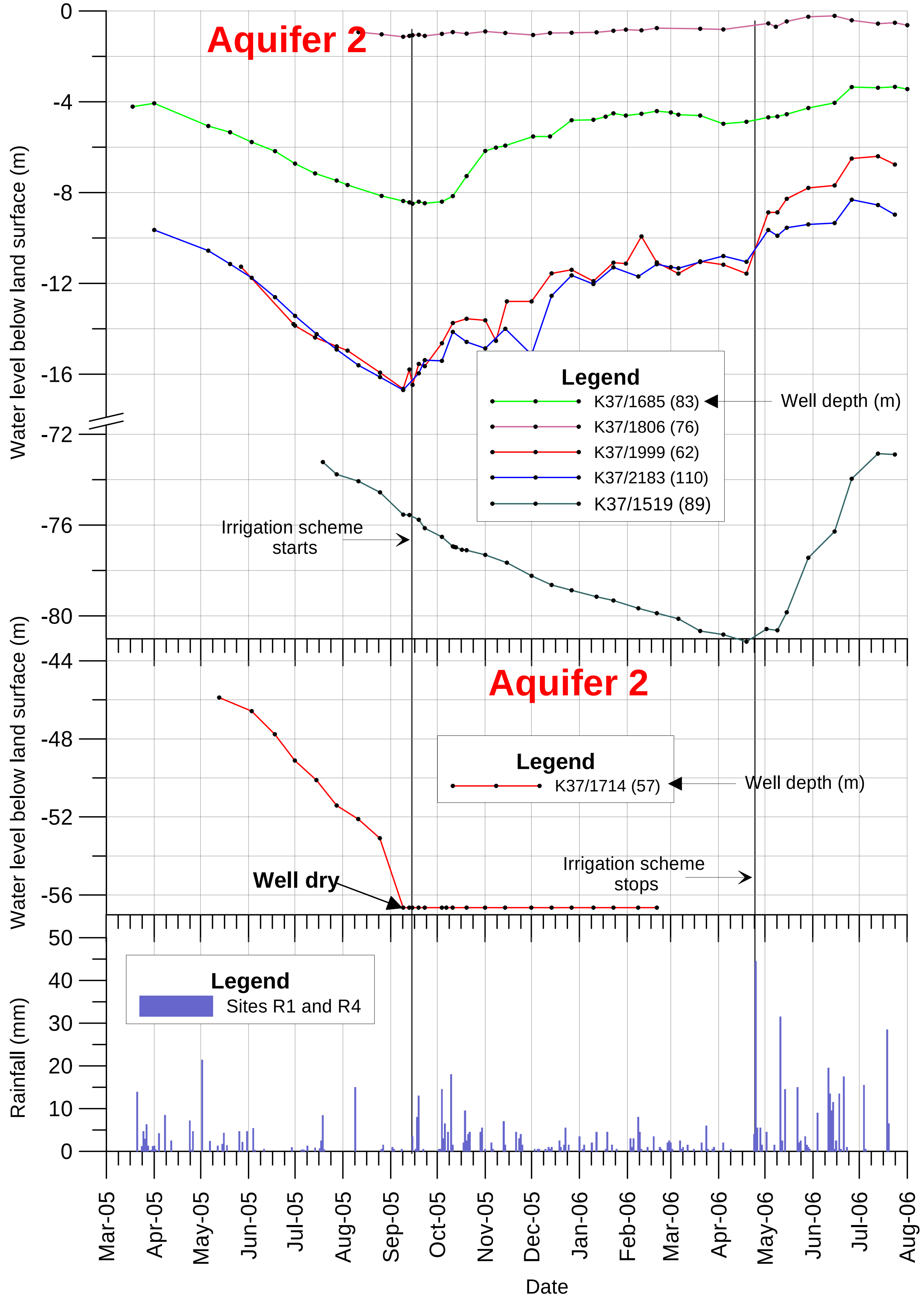

Figure 5.2 - Water level fluctuations in all second aquifer wells. Well K37/1714 is located within the second separate aquifer in Hydrogeological Section 4A.

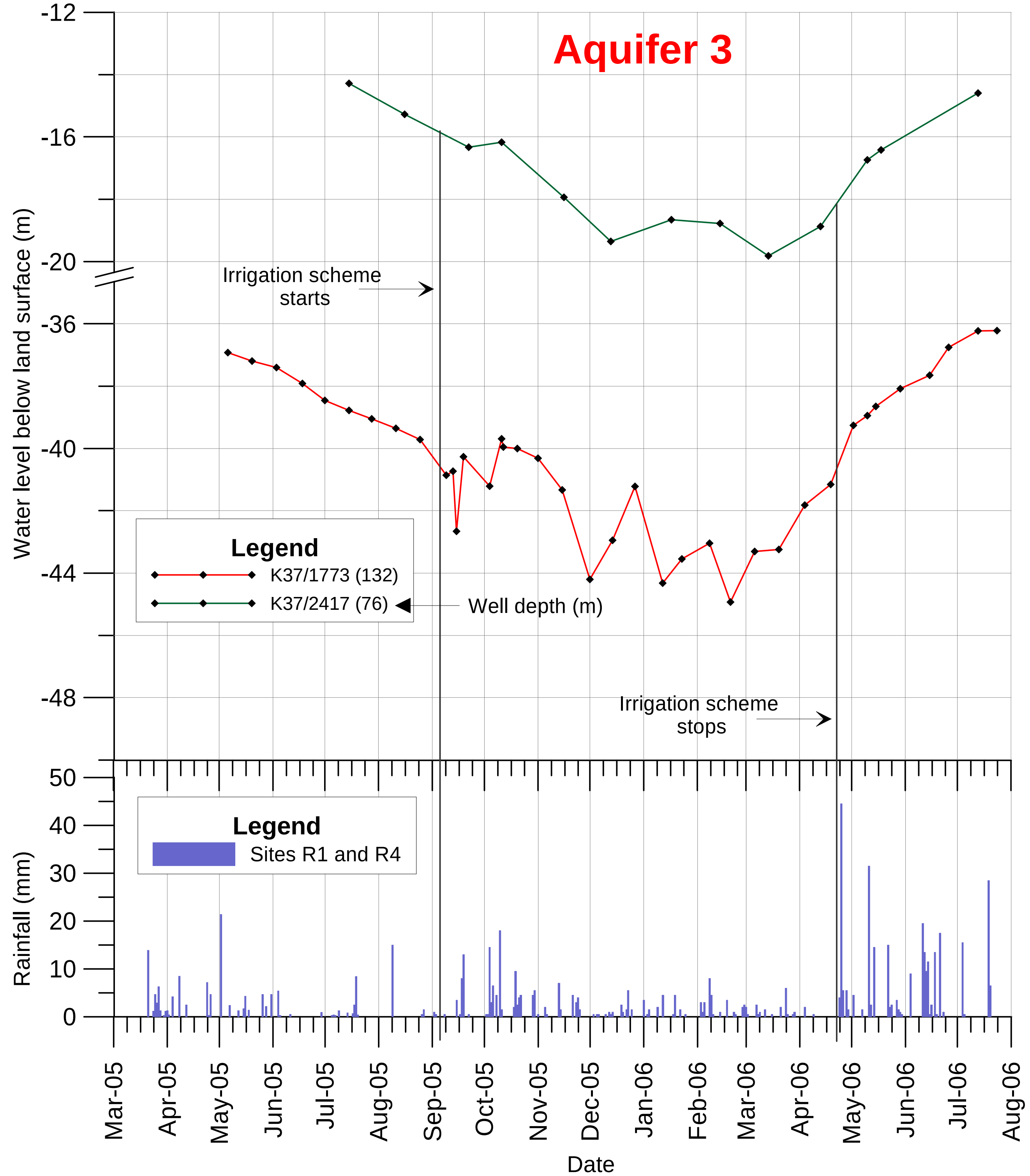

Figure 5.3 - Water level fluctuations in all third aquifer wells.

5.3.2 Aquifer Two

The water level fluctuations in all second aquifer wells are provided in Figure 5.2. During winter 2005, groundwater levels were only taken from wells located within Zone 1. Over this period, groundwater levels dropped between 4 – 6 m in response to record low rainfall, and an absence of scheme recharge.

Over the 2005/06 irrigation season, water levels in Zone 1 rose by approximately 6 m in response to Mayfield-Hinds Scheme recharge with out any observable effects from rainfall. The lack of rainfall influence likely reflected the low rainfall and dominance of scheme recharge during this period. The water level in well K38/1806, located within Zone 3, was highly effected by both border-dyke recharge and tidal effects. However, short-term responses to local rainfall events are easily discernable from automated water level data shown in Figures 5.7 and 5.8. On average, the water level in this well rose between 20 and 40 cm in response to local rainfall events greater than 25 mm (Figure 5.7). In contrast, the water level in well K37/1519, located within Zone 5, dropped 7.9 m over the 2005/06 irrigation season. With no second aquifer wells within a 2 km radius and very few second aquifer irrigation wells in total in this area, it is likely that the water level dropped in response to low rainfall.

Between April and July 2006, heavy winter rainfall caused a significant water level rise in aquifer two. The water level rise was greatest inland near Mayfield (12 m rise) and progressively reduced towards the coast (0.6 m rise) (Table 5.2).

Table 5.2 – Spatial variation in the water level response within aquifer two caused from heavy winter (2006) rainfall.

Well	Zone	Distance Inland From Coast (km)	Water Level Rise (m)
K37/1519	5	37	12.2
K37/1999	1	24	5.6
K37/2183		21	2.7
K37/1685		13	1.6
K37/1806	3	2	0.6

The exact cause of this is not known, however the following explanation could be a contributing factor. Closer to the coast in aquifer one, significant quantities of groundwater are discharged via springs, causing groundwater fluctuations to remain relatively small in comparison to inland fluctuations. In contrast groundwater from aquifer two does not discharge via springs, however the water level in this aquifer is very similar to aquifer one, and at some locations within Zone 3, the water level is higher than aquifer one. Thus nearer the coast, upward hydraulic gradients may be causing groundwater to discharged from aquifer two into aquifer one. Once in aquifer one this groundwater can then be discharge at the land surface via springs. This may be one reason why coastal groundwater fluctuations are smaller.

5.3.3 Aquifer Three

Groundwater fluctuations in third aquifer wells, K37/1773 and K37/2417 are provided in Figure 5.3. Over winter 2005, the water level in well K37/1773 dropped 3.9 m in response to both below average rainfall and an absence of scheme recharge. From September 2005 to February 2006, the water level dropped 4.2 m before rising 8.8 m between February and August 2006. From September 2005 to March 2006, the water level in well K37/2417 dropped 3.5 m, before rising 5.5 m between March and August 2006.

Based on little prior rainfall within the lower section of plains, coastward of Site R4, the water level rise in late summer was either caused by a delayed recharge effect from scheme recharge, rainfall recharge further inland on the plains or a combination of the two. The exact cause of the delayed rise is unknown, however possible evidence for a delayed scheme recharge effect is provided in Section 5.4.2. In contrast, the continued water level rise from April to August was almost certainly related to heavy winter rainfall.

5.4 Border-dyke Irrigation Affects

5.4.1 Aquifer Two – Zone 1

<u>Regional fluctuations</u>

Over the course of the 2005/06 irrigation season, water level fluctuations in all second aquifer wells followed the same pattern as aquifer one, the only exception was well K37/1714 (Figure

5.2). The summer water level rise was greatest further inland near Carew (6.5 m) and progressively reduced towards the coast (3.6 m) (Table 5.3).

Table 5.3 - Spatial variation in the water level response within aquifer two caused from Mayfield-Hinds Scheme recharge.

Well	Distance Inland From Coast (km)	Water Level Rise (m)
K37/1999	24	6.5
K37/2183	21	5.7
K37/1685	13	3.6

In contrast, well K37/1714 (57 m deep) located within Hydrogeological Section 4A (refer to refer to Figure 3.2 in back pocket), went dry approximately one week prior to the scheme commencing (Figure 5.2). Second aquifer water levels in Hydrogeological Section 4A are distinctly deeper than in aquifer two over the remaining Hinds Rangitata Plain. For a more detailed description of these differences, refer to Chapter 3.2.5. This well remained dry until at least mid February 2006, at which time water level readings were discontinued due to technical difficulties. In the early part of the season attempts were made to artificially recharge the well by continued border-dyke watering of the paddock directly up-gradient of the well. Despite of this, well K37/1714 remained dry. Over the past 5 years many residents in this area reported that their wells (in this aquifer) go dry in early summer and that water levels start rising from between February and January. This would suggest that this aquifer responds in a similar way to aquifer three, with a delayed water level rise in response to Mayfield-Hinds Scheme recharge.

The absence of an early summer rise was not caused by a lack of local border-dyke irrigation in this area as evident in Figure 1.12. However one farmer noted that some up-gradient border-dyke paddocks had been removed and one area of border-dyke paddocks nearby was not irrigated until later in the season. This may have contributed to the well remaining dry. Pumping effects can not be ruled out, however second aquifer wells in this area are all almost exclusively used for domestic or stockwater supplies. An area of significant groundwater abstraction from aquifer three occurs approximately 3 km SW of the well. If groundwater abstraction in this area is having an effect then this may suggest a connection between the separate second aquifer and aquifer three.

A connection between the separate second aquifer (in Hydrogeological Section 4A) and aquifer three is also suggested by the similar Hydrogeological characteristics of both aquifers. The second separate aquifer has a deep water level similar to that of aquifer three, and the water level in aquifer three during the course of this study did not start rising until mid February 2006 (Appendix 4.9). Bore log data in analyzed in Chapter 3.2.5 showed no lithological differences between this separate second aquifer and the second aquifer over the remaining field area. Thus the reason for the deeper static water level and delayed recharge response is not known at this stage.

Local border-dyke recharge

Automated water level data from well K37/1999 (69 m deep), dates for irrigating border-dyke paddocks, and pumping dates for nearby wells in the same aquifer were graphed to determine local border-dyke (pressure induced) recharge and pumping effects (Figure 5.4). The location of each border-dyke irrigated paddock is provided in Appendix 5.1. Irrigation dates show that some local recharge effect is likely from the irrigation of paddocks C1, E1 and D1, up-gradient of the well. However an estimation of the amount of rise and over what period of time is difficult because of the drawdown and sharp rises associated with the intermittent pumping of irrigation well K37/2136 (59 m deep) 500 m down-gradient (in the same aquifer). Pumping resulted in an average drawdown of 1 m, with the greatest amount of drawdown or recovery occurring in the first few hours. Yet despite this pumping effect, overall groundwater levels still rose as a result of scheme recharge.

5.4.2 Aquifer Two – Zone 3

The water level in well K38/1806, 2.0 km inland from the coast, consistently rose by 32 cm over the 2005/06 irrigation season (Figure 5.2). Two factors may have contributed to the steady summer rise. Firstly, the water level may have risen from a localized pressure effect, in response to drain water sourced border-dyke irrigation which occurs near this well. In addition, this well is located 15 m up-gradient of a border-dyke paddock. Within Zone 3, the small local area of border-dyke irrigation occurs within the dashed boundary labeled A (Figure 5.1). Secondly this rise could have been caused by Mayfield-Hinds Scheme recharge. If so, then this would suggest that border-dyke recharge further inland is causing a pressure wave which propagates coastward

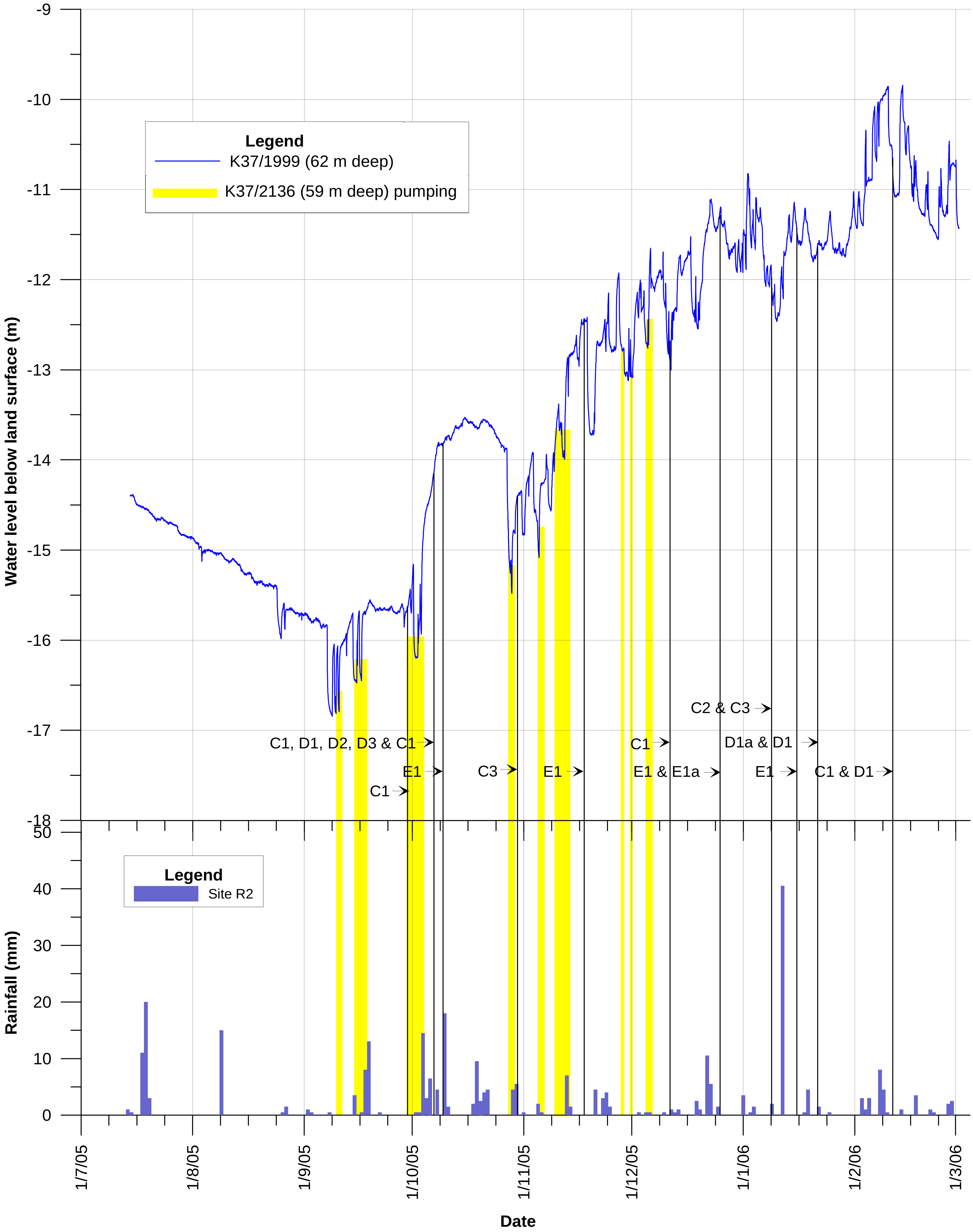

Figure 5.4 - A comparison of water level plots with local rainfall, border-dyke irrigation and pumping affects.

past the edge of the scheme boundary. Water level rises in aquifer two caused by tidal changes propagate at least 2.1 km inland from the coast, thus a pressure effect from the water levels rising in Zone 1, may do likewise. However in the absence of long-term data, and the likely effects from local border-dyke irrigation, it is difficult to determine the exact cause of this rise.

5.4.3 Aquifer Three – Zone 1

Groundwater levels from aquifer three were taken from wells K37/1773 (135 m deep) and K37/2417 (76 m deep) (Figure 5.3). Over the winter 2005, the water level in well K37/1773 dropped 3.9 m. Between September 2005 and February 2006, the water level dropped 4.2 m, before rising 8.8 m between February and August 2006. From September 2005 to March 2006, the water level in well K37/2417 dropped 3.5 m, before rising 5.5 m between March and August 2006.

The overall water level drop over much of the summer was either caused by groundwater abstraction affects, or delayed scheme recharge affect, related to the geological differences of aquifer three. In well K37/1773, the water level declined in a saw tooth pattern over much of 2005/06 irrigation season. This most likely occurred from local pumping effects as evident by the 1.9 m water level drop over 2 days, between the 13 and 15 of September 2005. This drawdown affect, may have been caused from one or a combination of nine, third aquifer irrigation wells, located within 4 km up-gradient of the well. Four third aquifer irrigation wells occurring within a 3 km radius of well K37/2417, suggesting that a groundwater abstraction at this location may occur also.

A delayed scheme recharge affect is potentially evident from the late summer rise in groundwater levels prior to significant rainfall in winter 2006. The cause of a delay could be related to the less permeable layer which generally overlies aquifer three, over much of the field area (refer to Figure 3.11). This layer may reduce the rate at which water is released into the aquifer, thus increasing the time taken for the scheme recharge to have an affect. Further more, water usage from the two centre pivots suggests that groundwater abstraction was similar or greater during the later part of the irrigation season (refer to Appendix 4.7). Thus a water level rise caused from reduced groundwater abstraction is unlikely. Continued monitoring of third aquifer wells is required to determine the exact cause of this delayed summer rise.

5.5 Comparisons between Aquifers One and Two

5.5.1 Recharge responses

Water level fluctuations in aquifer two (with the exception of Hydrogeological Section 4A) are almost identical to aquifer one, suggesting the two aquifers are highly connected (Figure 5.5). A comparison of the response time to recharge events between wells K37/0232 (9 m deep) and K37/1685 (84 m deep), 500 m apart is shown in Figures 5.5 and 5.6. A slightly lower water level, bore-log data (provided in Appendix 5.2) showing a confining layer of heavy clay between 27 and 34 m depth, significant amounts of claybound gravels from 34 to 70 m depth, and a screen from 76 – 83 m all show that well K37/1685 is in aquifer two. The difference in water levels between the two wells varied between 1.3 m and 15 cm. This suggests that for periods of time, water levels in aquifer two may be higher than aquifer one, with a change from a downward to upward hydraulic gradient. This change in the hydraulic gradient between aquifers one and two (induced by summer groundwater abstraction) occurs between the Hinds and Ashburton Rivers at approximately the same distance inland from the coast (Davey, 2006 c).

In general the water level rise and fall in aquifer two usually occurs between 1 and 5 days after aquifer one. The first water level rise in response to Mayfield-Hinds Scheme recharge occurred approximately 4 days earlier in K37/0232 compared with K37/1685 (Figure 5.6). In addition, the water level in well K38/1310 (9 m deep) in aquifer one, rose three days earlier than well K38/1806 (76 m deep) in aquifer two, in response to a 12 mm rainfall event (Figure 5.8). These two wells occur 1.5 km apart. The delayed water level rise and fall in aquifer two is thought to be a pressure effect. This occurs as water infiltrating aquifer one causes the total weight of the first aquifer to increase. This compresses the underlying second aquifer, causing water levels to rise without any direct recharge of water into the deeper aquifer (McWhorter and Sunada, 1977).

However, at certain times, water levels in aquifer two may rise or fall earlier than aquifer one. For example, in response to a 20 mm rainfall in mid September 2005, the water level in well K37/1685 rose four hours prior to well K37/0232 (Figure 5.6). Earlier water level rises in aquifer two are not possible from a local pressure effect or direct recharge. In both cases aquifer one must be recharged first, thus causing the water level in aquifer one to rise sooner. The exact reason for this is not known, however it could be related to recharge further inland on the Plains.

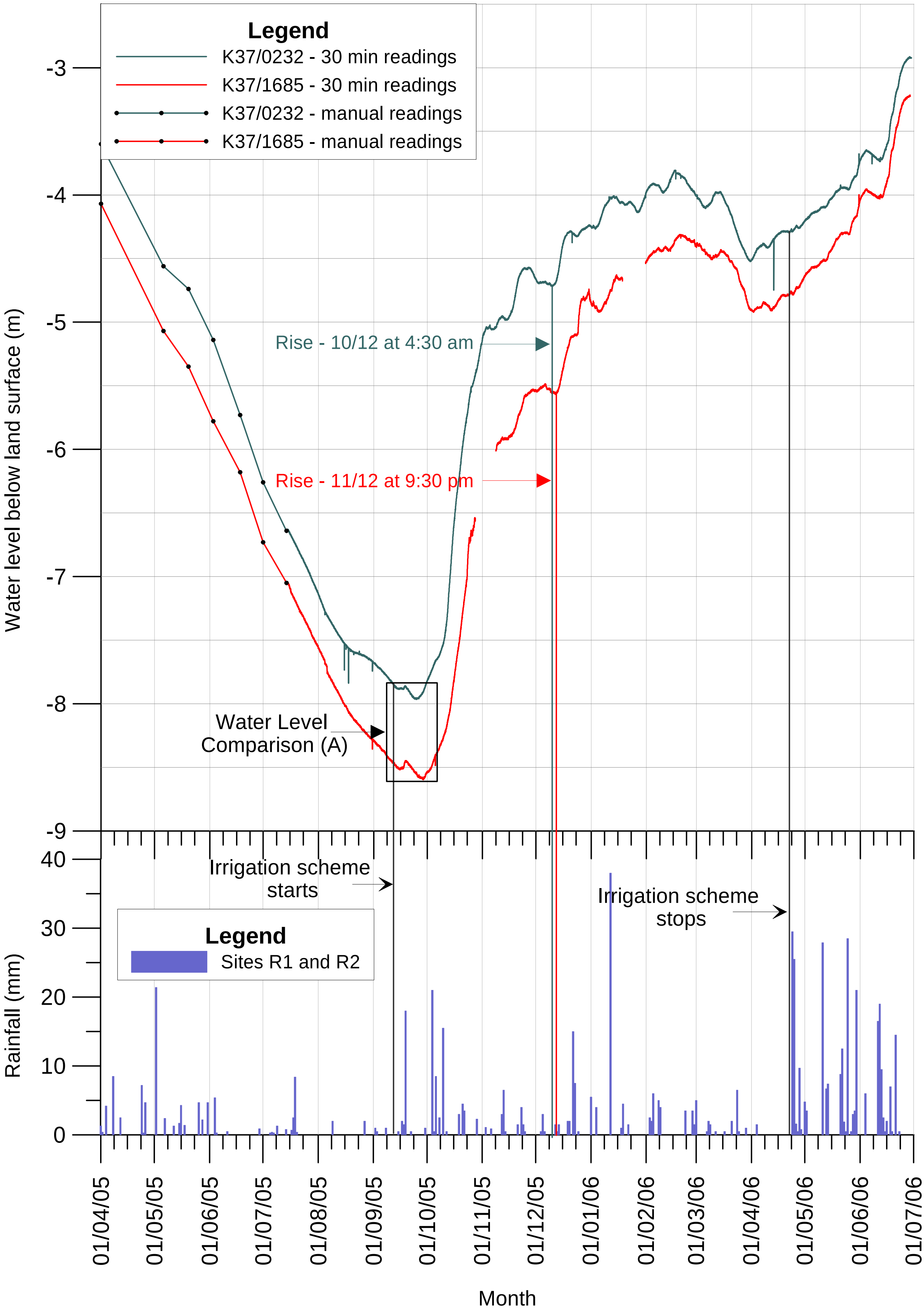

Figure 5.5 - Comparison between the water level fluctuations in a first and second aquifer well, 500 m distance apart.

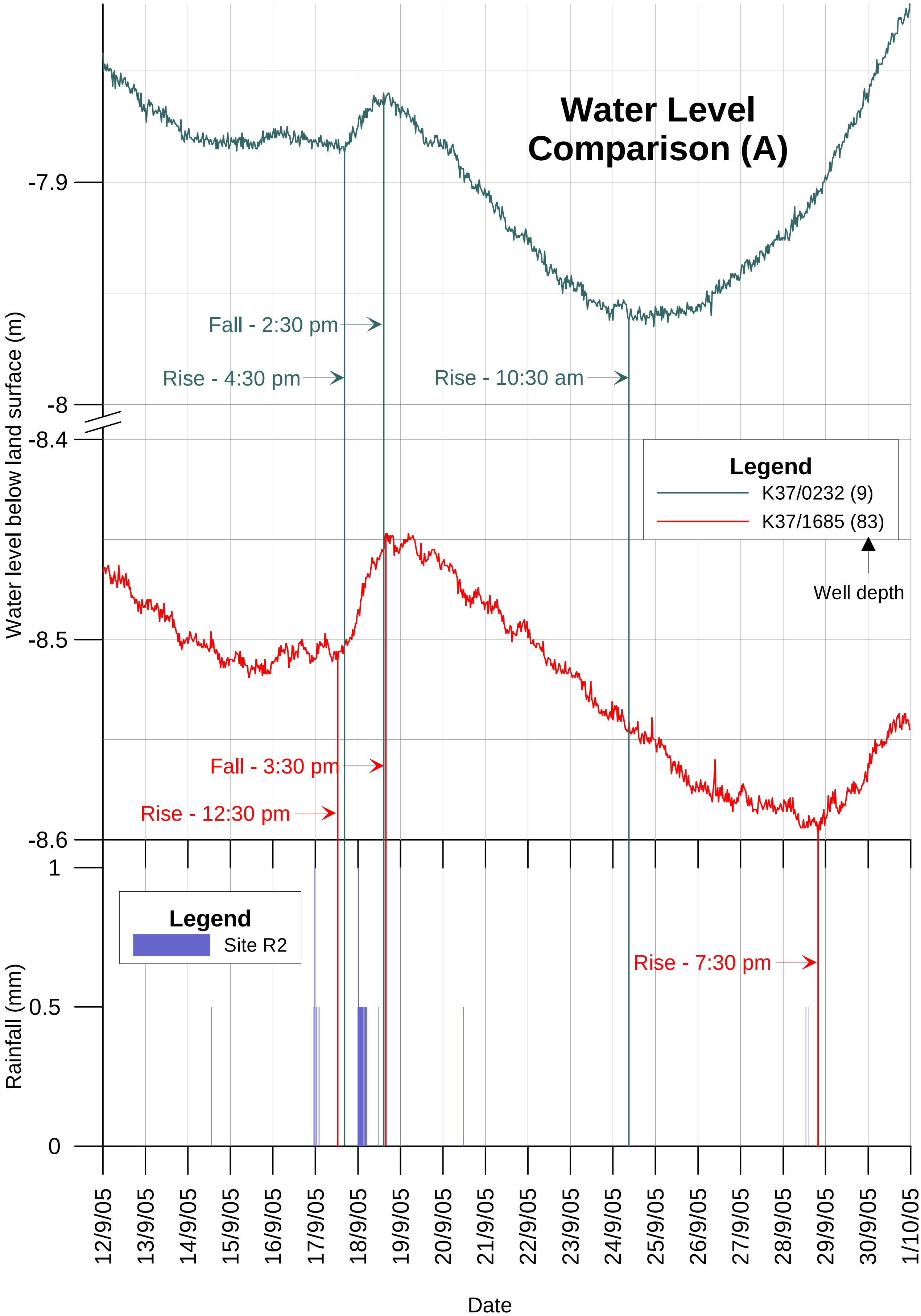

Figure 5.6 - A comparison between the short-term recharge response of aquifers one and two.

5.5.2 Hydrogeological influences

The similarity in water level fluctuations between aquifers one and two was likely caused by the relatively similar water levels in both aquifers. As a consequence the hydraulic gradient between the aquifers is very small. The smaller hydraulic gradient allows water to move more freely between the first and second aquifer. In addition, bore log data suggests the sediment separating aquifers one and two is relatively permeable. This again would allow water to move more freely between the first and second aquifers.

In contrast, water level fluctuations in the second separate aquifer near Lismore do not appear to follow aquifer one, with water levels dropping despite the first aquifer water levels rising. Here the water level in aquifer two is far lower than aquifer one. As a consequence the hydraulic gradient between the aquifers is large. The larger hydraulic gradient allows water to move less freely between the first and second aquifer. This would explain the delayed water level rise in response to scheme recharge. No distinct confining layer between the two aquifers could be recognized in the area where this aquifer occurs. More research into the geological differences between these aquifers is required.

5.6 Tidal Affects

5.6.1 Aquifer two

Mean tide height data from the Rangitata River Mouth (NIWA, 2006) was compared to the tidal fluctuations in well K38/1310 (8 m deep) in aquifer one, 120 m inland from the coast and well K38/1806 (76 m deep) in aquifer two, 2.0 km inland from the coast (Figures 5.7 and 5.8). An approximately 12 hour time delay occurred between high tide and the water level rise in well K38/1806 (aquifer two). The tidal water level fluctuation was 2 - 3 cm. In contrast there was an approximately 2 hour time delay between high tide and the water level rise in well K38/1310 (aquifer one). The tidal water level fluctuation was 5 – 7 cm, with larger tidal fluctuations causing larger water level fluctuations.

The tidal water level fluctuation in well K38/1806 (semi-confined aquifer two) is caused by a pressure wave propagating through the aquifer, the amplitude of which decreases with increasing distance from the coastline (McWhorter and Sunada, 1977). The pressure wave is created by the

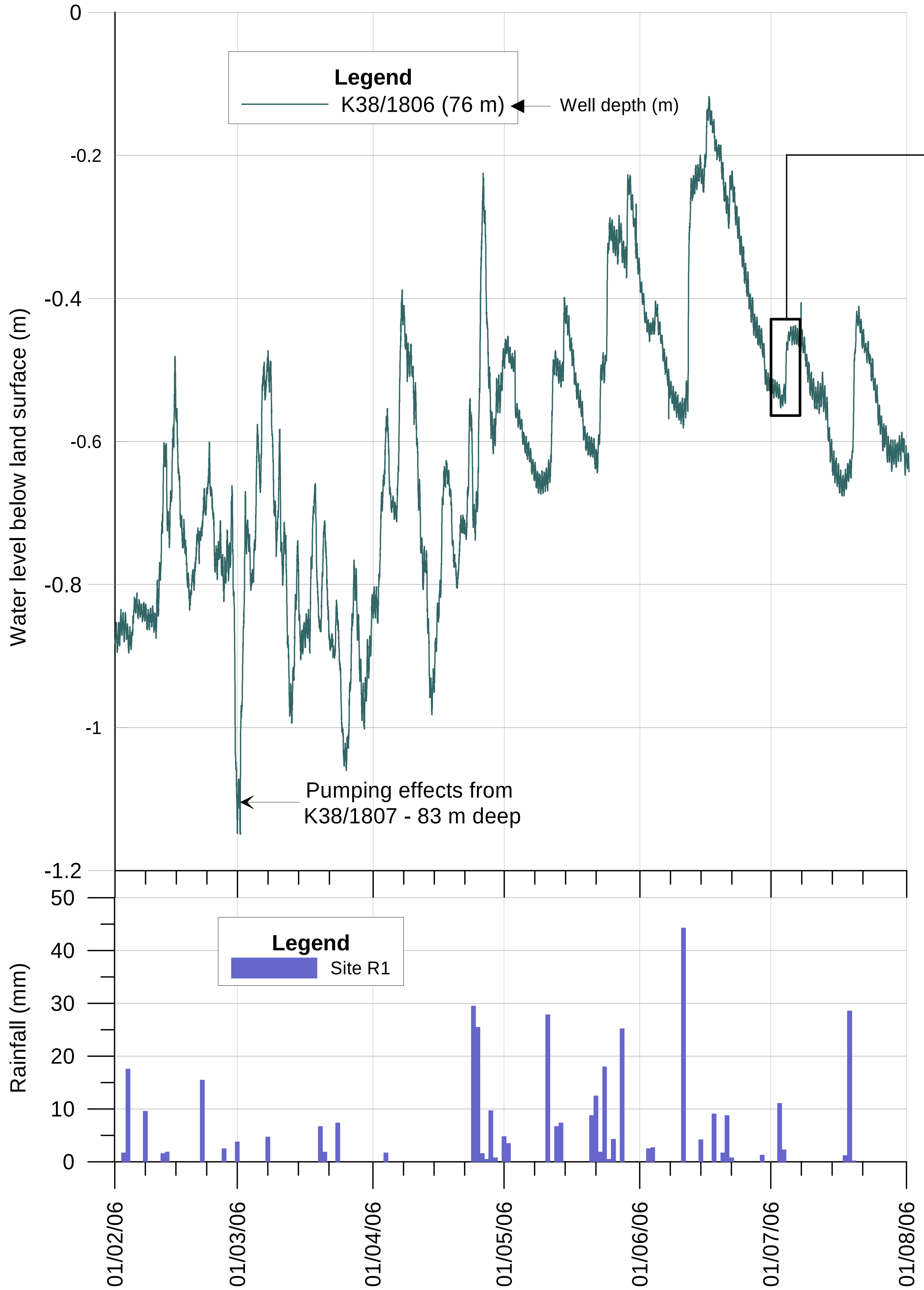

Figure 5.7 - Tidal effects and groundwater level fluctuations in aquifer two.

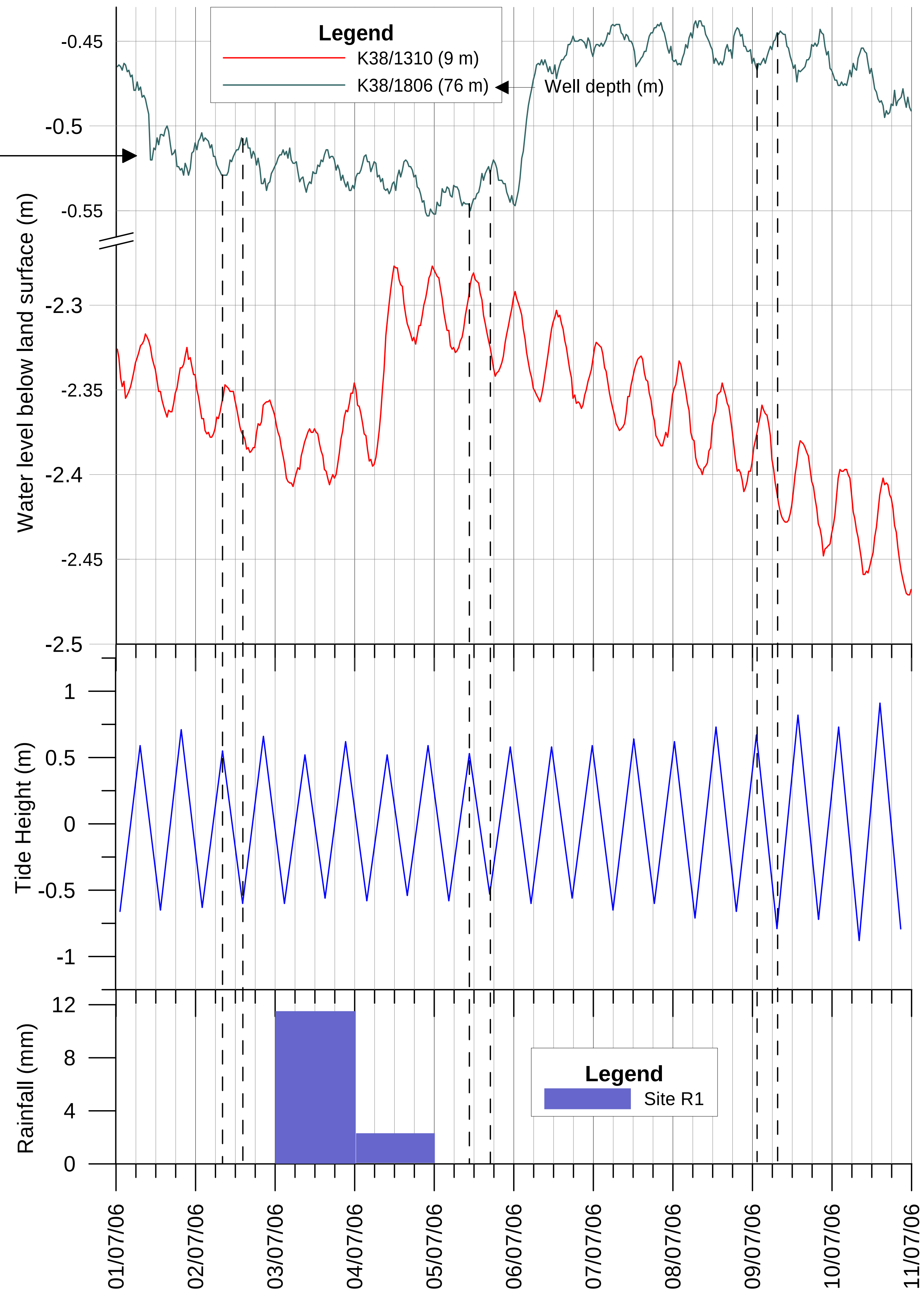

Figure 5.8 - Tidal affects on the aquifers one and two.

loading and unloading of the aquifer as the tide rises and falls (McWhorter and Sunada, 1977). In the case of well K38/1806 this pressure wave takes approximately 12 hours to reach the well, causing the water levels to be highest when the tide is lowest. Had well K38/1806 been closer to the coast, the water level would have risen higher and earlier in response to an increasing tide height.

5.7 Summary and Conclusions

5.7.1 – Aquifer Two

Second aquifer water levels in Zone 1, follow the same seasonal fluctuations as aquifer one. In general, the water level will drop over winter and rise each summer in response to Mayfield-Hinds Scheme recharge. The only exception was in Hydrogeological Section 4A, where second aquifer groundwater levels likely rise in late summer, following a similar pattern to aquifer three. In Zone 5, water levels only responded to rainfall, suggesting that rainfall is the dominant source of recharge. In Zone 3, the dominant source of recharge is not known. Within this zone recharge from rainfall does occur, and possibly from local border-dyke irrigation. However, it is not known whether this zone receives any recharge from the Mayfield-Hinds Scheme. In general the water level rise and fall in aquifer two usually occurs between 1 and 5 days after aquifer one

Rainfall recharge effects aquifer two over the entire Hinds Rangitata Plain. In response to heavy winter (2006) rainfall, water levels rose greatest inland near Mayfield (12 m rise) and progressively reduced towards the coast (0.6 m rise).

2 km inland from the coast in Zone 3, a comparison of tidal data and groundwater levels shows an approximately 12 hour time delay between high tide and the high groundwater level. The 2 - 3 cm tidal groundwater fluctuation was caused by a pressure wave propagating through the aquifer, the amplitude of which decreases with increasing distance from the coastline.

5.7.2 – Aquifer Three

Groundwater fluctuations in aquifer three were only monitored in Zone 1. Within this zone, groundwater recharge occurs from rainfall, and possibly the Mayfield-Hinds Scheme. A scheme recharge affect is potentially evident from the late summer rise in groundwater levels prior to significant rainfall in winter 2006. However, local groundwater abstraction affects make it difficult to exactly determine the reason for this delayed rise. Continued monitoring of third aquifer wells is required to determine the exact cause of this delayed summer rise.

Chapter Six

Surface Hydrology and Springs

6.1 Introduction

This chapter outlines the nature and occurrence of springs, seasonal drain flow fluctuations, flow regimes of the Hinds and Rangitata Rivers and the possible flow losses from on-farm distribution races. Changes in both drain and river flows were related to the changes in groundwater levels. This information is used to gain a better understanding of the surface and groundwater interactions within the field area.

6.2 Springs

Previous studies on the Hinds Rangitata Plain springs have been carried out by Oliver (1946 c), Aitchison-Earl (2000) and Davey (2003). Springs occur as depression or contact springs located in natural gullies or in the bed of the Hinds River, or as terrace riser springs emanating from the base of the Rangitata River Terrace (Figure 6.1).

6.2.1 Plains depression and contact springs

The majority of depression and contact springs occur between Coldstream Rd and the old Hinds Swamp (Figure 6.1). Often these springs occur at the point of contact between gravels of greater or lesser permeability, or as seepage from natural depressions or gullies (Davey, 2003). Depression springs within Zone 1 (Zone 1 boundary shown in Figure 4.1 in the back pocket) are highly affected by the combination of summer border-dyke recharge and winter rainfall. Coastward of the scheme in Zone 3 where the water table is consistently higher, springs are predominantly affected by rainfall. These springs in combination with tile drains, contribute a significant quantity of groundwater into the Hinds Drainage Network. Between the Hinds and Rangitata Rivers this drainage network is comprised of 15 drains that flow to the sea and 3 drains that flow into the Hinds River.

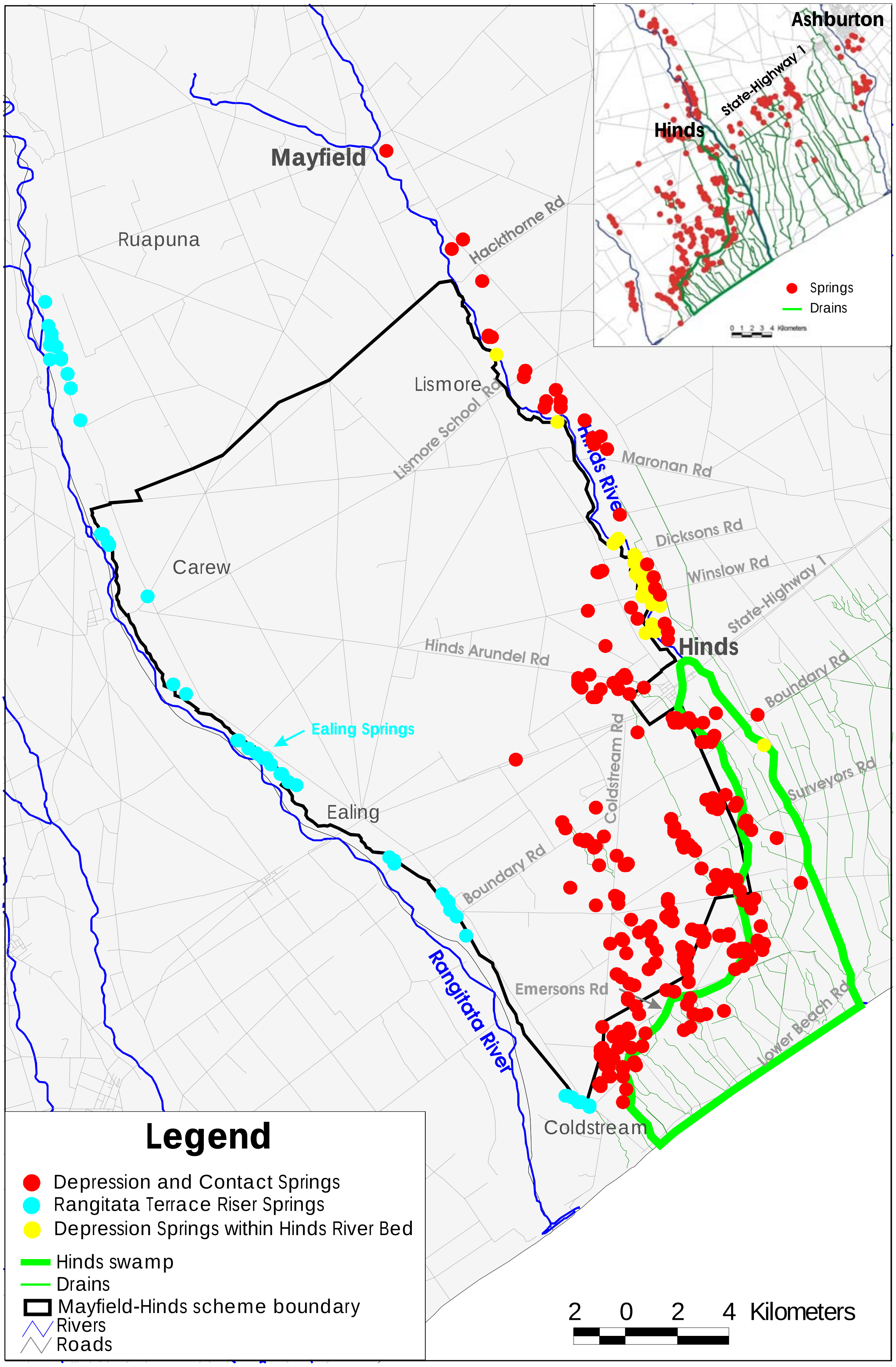

Figure 6.1 - Distribution of springs and drains within the Hinds Plains.

6.2.2 Hinds River depression and contact springs

Depression and contact springs also occur within the active bed and adjacent to the Hinds River in relict river channels (Figure 6.1). From Mayfield Township downstream to Hackthorne Rd a number of springs occur adjacent to the Hinds River, however these are yet to be mapped or described. Landowners suggest these springs are dominantly rainfall and Hinds River recharged. Springs between Hackthorne Rd and Maronan Rd emanate from the north bank of the Hinds River and their discharge is highly affected by flow in the Hinds River. The majority of river bed springs occur 2 km upstream and downstream of Winslow Rd. Landowners (cited in Davey, 2003) reported that these springs are semi-permanent and flow nearly all year round. During the course of this study these springs were significantly affected by scheme recharge. During dry periods, springs consistently flowed from the bed of the river half way between Boundary Rd and Surveyors Rd. Downstream from these springs the river flowed all the way to the sea.

6.2.3 Rangitata River terrace riser springs

From Coldstream to Ruapuna, springs also occur where the water table intersects the base of the Rangitata Terrace (Figure 6.1). Terrace riser springs feed drains which flow into the Rangitata River; the only exception is Oakdale Drain which seeps through a gravel barrier bar into the ocean. The majority of these springs are affected by the Mayfield-Hinds scheme, evident by the summer rise in groundwater levels adjacent to the river, piezometric groundwater flow contours and gaugings of Oakdale Drain which showed a doubling in flow over the 2005/06 irrigation season. In addition, local farmers describe an increase in flow from terrace riser springs near Boundary Rd each irrigation season.

6.2.4 Dominant sources of recharge

As part of a survey carried out in early 2006 (Dodson, 2006), farmers where asked what they believed was the dominant source of recharge for springs on their property (Figure 6.2) Within and just Zone 1, farmers believed that border-dyke and a combination of border-dyke and rainfall recharge were dominant sources. Within and just Zone 3, farmers believed that springs were most affected by a combination of border-dyke and rainfall recharge with a group of dominantly rainfall recharged

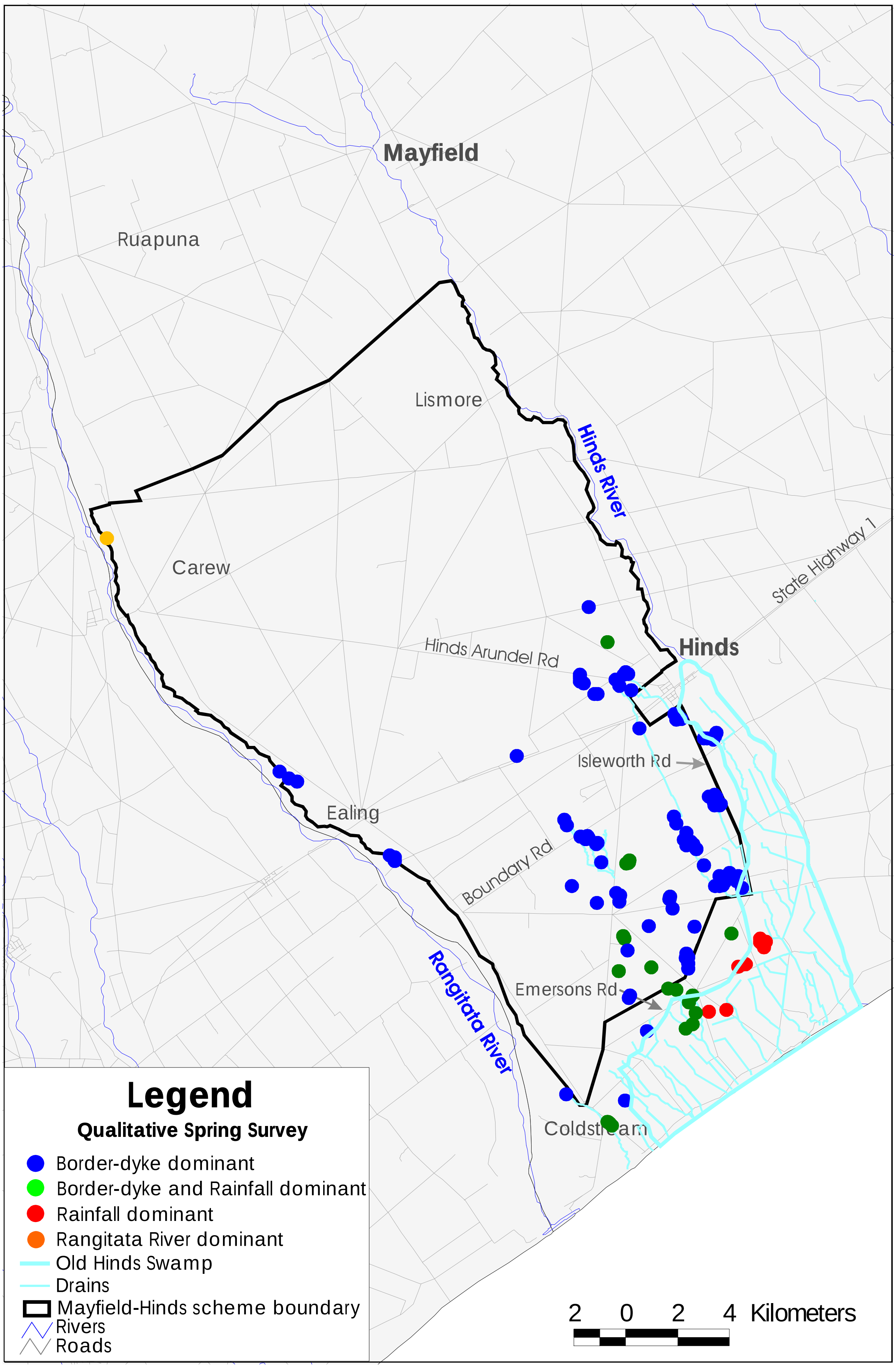

Figure 6.2 - Landowner opinions on the dominant recharge sources for springs.

springs just coastward and east of Lowcliffe. These reports suggest the same dominant recharge sources as determined from groundwater level fluctuations.

6.3 Seasonal Drain Flows

Five drains (Boundary Drain, Northern Drain, Griggs Drain, Heddlee-Smythe Drain and Oakdale Drain) were gauged every two weeks from approximately September 2005 to August 2006 and time series photos were taken at an unnamed drain in order to evaluate seasonal fluctuations and sources of recharge (Figure 6.3). The tabulated results are provided in Appendix 6.1. Between May and August 2006 gaugings were carried out by Environment Canterbury. Two gauging sites each on Moffats Drain and Northern Drain enabled a comparison of the flow and recharge sources at different sections along the drain. In order to accurately compare the change in flow over time, all gauging sites were located upstream of any surface water takes. In addition, automated flow data taken by Environment Canterbury from Boundary Drain and Stormy Drain was also used (Figure 6.3).

6.3.1 Gauging methodology

Gauging sites were selected where the flow followed a straight channel and where plant growth or other obstacles were absent. During summer, weeds were cleared 1 – 2 m upstream of the gauging site and 3 – 4 m downstream. Gaugings were conducted using a NIWA (National Institute of Water and Atmospheric Research) current meter and small horizontal axis Ott propeller and are considered accurate to +/- 8 percent. At least twenty flow verticals were taken across the width of the channel at 60 percent the depth of the water. Flow rates were calculated by the velocity-area method using the gauging calculation software gLog (Scott Technical New Zealand Ltd).

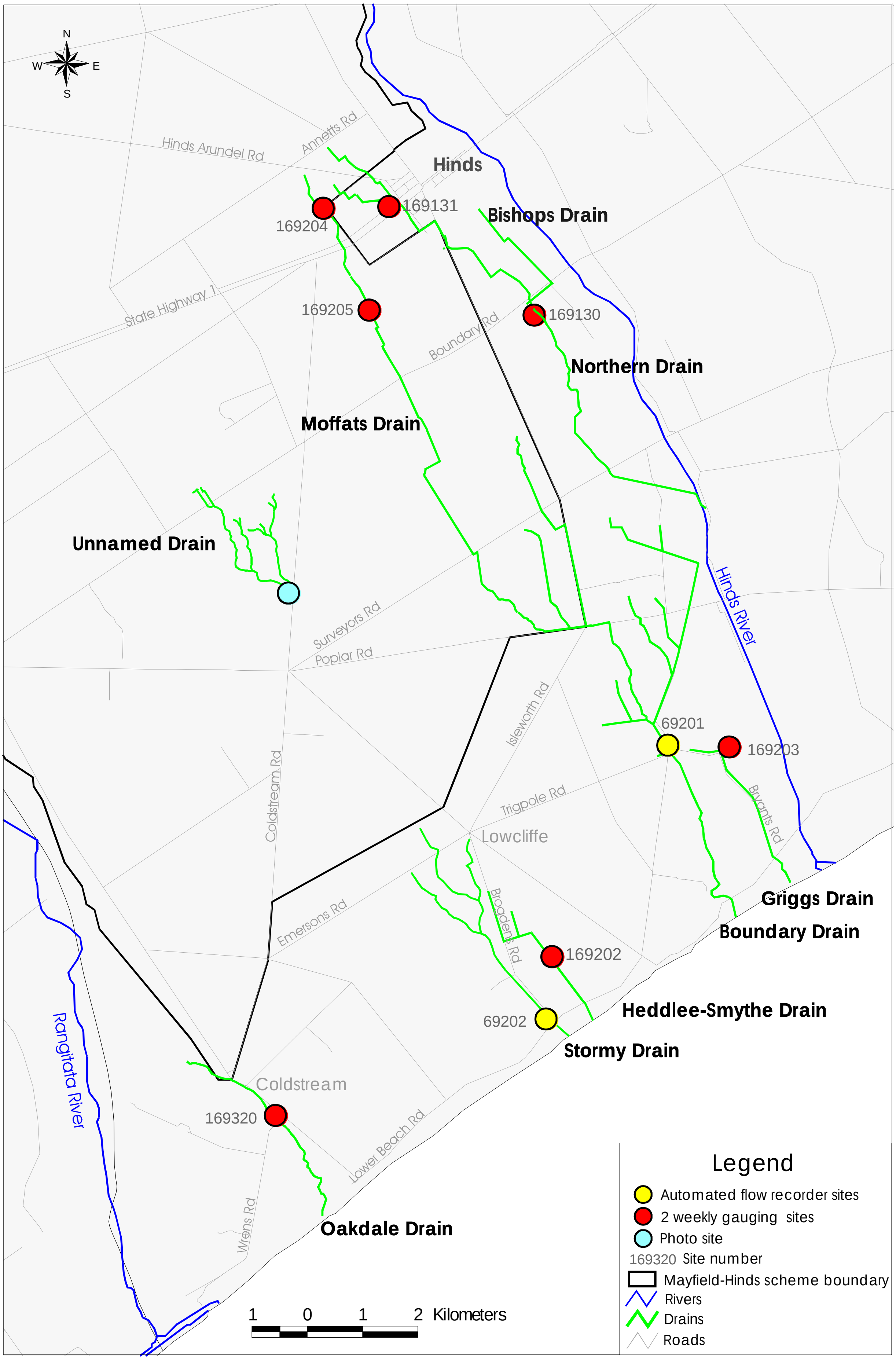

Figure 7.2 - Location of drains, gauging sites, flow recorder sites and nearby wells.

6.3.2 Moffats Drain

Geomorphology and Hydrogeology

Moffats Drain is 13 km long and starts at Hinds Arundel Rd before flowing into Boundary Drain 800 m upstream of Trigpole Rd (Figure 6.3). A number of spring fed drains and natural gullies feed into Moffats Drain over its entire length, causing the flow to increase downstream. Upstream of the two gauging sites, groundwater inflow is sourced from depression springs, novaflo (perforated drainage pipe), tile drains, seepage from the drain banks and artesian springs within the base of the drain (Appendix 6.2). Springs upstream of Gills Rd occur within a high water table area that extends from Moffats Drain to the Hinds River. Both Oliver (1946 c) and Davey (2003) suggested these springs result from the presence of ironstone which keeps groundwater levels higher than the surrounding area. Evidence of an iron-pan at this location is provided from drillers reports in Oliver (1946 c), from freshly dug drain cuttings near Hinds Township and landowner accounts of digging through concrete-like layers.

Additional evidence of ironstone layers was made from observations of a flowing artesian spring (K37/2978) within the bed of Moffats Drain which was located adjacent to a flowing depression spring (K37/1906) (Appendix 6.2 photos B and C). During September 2005, the water table at this location was at its lowest point (Figure 6.4) and the drain and both the depression and artesian springs were dry. By May 2006 the water table had risen approximately 4.5 m, 4 m of that rise occurring over the irrigation season as a result of scheme recharge (Figure 6.4). By this time both springs were active with water seen bubbling up through the gravel bed of the drain. Immediately adjacent to the drain, the water table intercepted the land surface at a topographic depression, creating a depression spring which flowed back into the drain. It is likely that the artesian spring is caused by a claybound gravel or ironstone confining layer separating two water-bearing layers within aquifer one. In order to create an upward flow from the deeper water-bearing layer the water level of the deeper layer is either higher than the confining layer or represented by the water table which in this case is causing the flowing depression spring adjacent to the drain. Water may bubble up at a break in the confining layer where water from the lower water bearing layer is forced upward under pressure. A schematic diagram (not to scale) is provided below (Figure 6.5).

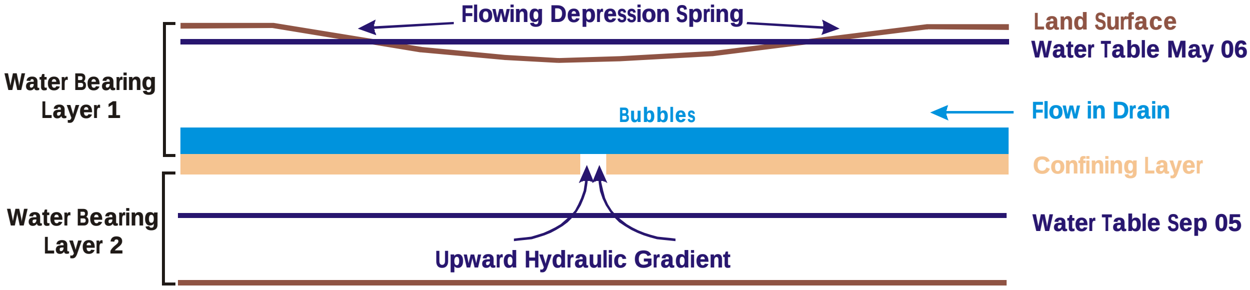

Figure 6.5 – Schematic diagram showing the potential occurrence of an artesian spring.

Seasonal Fluctuations in Flow

From early December 2005 to August 2006 two weekly gaugings were taken at Gills Rd (site M1). At the Chisnall Property (site M2) half way between State-Highway 1 and Boundary Rd two weekly gaugings were taken from late December 2005 to August 2006 (Figure 6.4). In mid September 2005 Moffats drain was dry (with the exception of 15 l/s of stockwater flowing in from Hinds Arundel Rd) from its source downstream to at least Boundary Rd (below which the drain may have been flowing). At this date the water level in well K37/2663 (10 m deep) was 6.4 m below ground level (Figure 6.4). By late November 2005 the water level in the well had risen 3.6 m, at which point groundwater first appeared seeping from the bottom of the drain at various locations between Gills Rd and Hinds Arundel Rd. This is where the flow of water started. This contrasts with the initiation of flow in the Northern Drain which moved progressively upstream as the water table rose (discussed in Section 6.3.3). Had the pre-irrigation groundwater level been higher then the drain would have started flowing earlier. Thus the time taken for a dry drain to start flowing is strongly affected by winter rainfall which influences the groundwater level at the beginning of the irrigation season.

Between December 2005 and February 2006 the groundwater level in well K37/2663 rose 1.26 m by which time the flow had reached 110 l/s and 150 l/s at Sites M1 and M2 respectively. A flow increase and corresponding groundwater level rise shows that Moffats Drain is highly affected by the scheme. Over the course of this study the flow at M2 was approximately 20 - 40 l/s greater than at site M1, 2 km upstream. This may have been caused by spring inflow or direct groundwater recharge (where the base of the drain intercepted the water table).

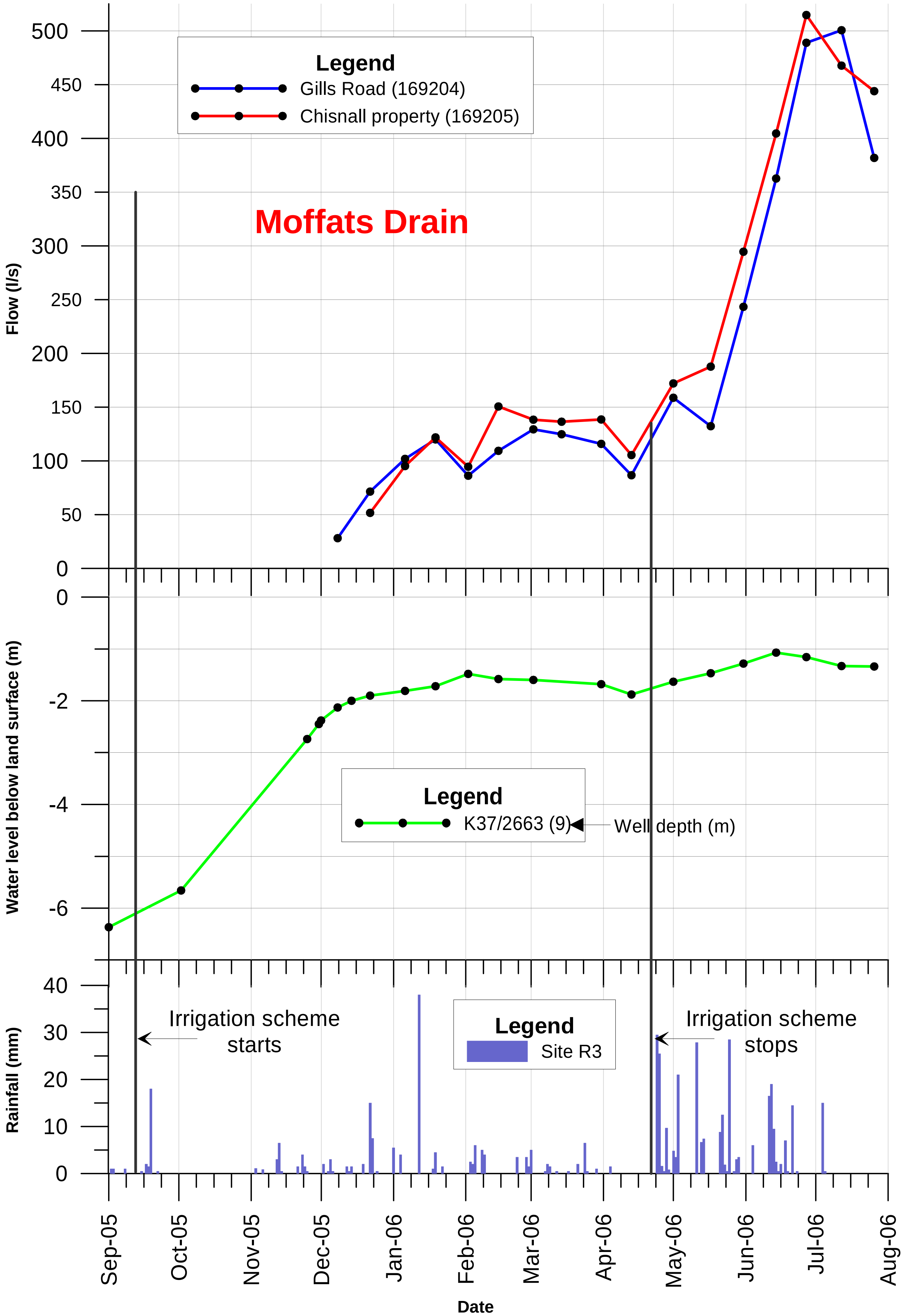

Figure 6.4 - Comparison of drain flow, groundwater levels and rainfall.

The drop in flow in early February 2006 was caused by the diversion of water (upstream) for border-dyke irrigation. From March to April 2006 the flow and corresponding groundwater level dropped slightly. Between May and July 2006, the flow at both sites increased to approximately 500 l/s, with a relatively small rise in the groundwater level. At the end of the irrigation season the groundwater table in the area above Gills Rd was less than 0.5 m below ground level (well K37/2663 is on a topographic high), meaning there was very little storage capacity within the aquifer to accommodate the large winter rainfall. As occurred with the Northern Drain (Section 6.3.3) the closer the water table is to the land surface the greater the spring discharge will be for a given rise in water levels. In conclusion it is likely that the large flow increase was caused by a combination of significant quantities of surface runoff and a large groundwater discharge relative to a small water table rise.

6.3.3 Northern Drain

<u>Geomorphology and Hydrogeology</u>

The Northern Drain is 11 km long and starts at Annetts Rd before merging with Montgomerys Drain and flowing into the Hinds River half way between Surveyors Rd and Poplar Rd (Figure 6.3). In addition, Bishops Drain (from which there was up to 150 l/s during winter 2006) flows into the Northern Drain on the upstream side of Boundary Rd. Upstream of the two gauging sites groundwater inflow is sourced from depression and artesian springs, novaflo (perforated drainage pipe), tile drains, permeable gravel lenses flowing from the sides of the drain and seepage from the banks of the drain (Appendix 6.3). Water flowing from permeable lenses (described in Section 2.6) intersecting the bank of the drain were observed in drain outcrops near Hinds Township (Appendix 6.4). These lenses comprise free, clay coated gravels up to 1 m wide and 30 cm thick. It is likely that a number of drains receive groundwater flow from permeable lenses such as these, however weed growth and vegetation make them difficult to identify. In addition, the degree to which groundwater abstraction affects an adjacent drain flow may be influenced by the number of streams or absence of streams contributing water to both the drain and well.

Seasonal Fluctuations in Flow

From September 2005 to August 2006 two weekly gaugings were taken at McConnells Rd (site N1). At Boundary Rd (site N2) two weekly gaugings were taken from November 2005 to August 2006 (Figure 6.6). Between September 2005 and early December 2005, the flow at site N1 was sourced from district council stock water and remained between 8 l/s and 21 l/s. From early December 2005 to January 2006 the drain flow increased to approximately 100 l/s as a result of Mayfield-Hinds scheme recharge, after which time the flow remained stable before rising to approximately 300 l/s as a consequence of heavy winter (2006) rainfall. Because N1 sourced most of its groundwater from the same area as M1 and M2, the seasonal fluctuations in flow at N1 follows a similar pattern to M1 and M2.

Between October and November 2005, the groundwater level in well K37/2405 (9 m deep) rose from -3.6 m to -1.3 m below ground level (2.3 m) during which period there was little or no flow at site N2. Between November 2005 and April 2006 the groundwater level in well K37/2405 rose (consistently) 51 cm and the flow at N2 increased from 79 l/s to 415 l/s. Between April and August 2006, heavy winter rainfall caused an additional 49 cm water level rise and the flow reached 991 l/s. Despite the rapid groundwater level rise between October and November 2005 the total quantity of recharge was most likely greatest between November 2005 and February 2006 and between April and June 2006 (Appendix 4.7). Thus the reason for the rapid groundwater level rise in the early stages of the irrigation season was because the greater depth to groundwater allowed a greater percentage of the recharge to be stored within the aquifer. Once the water table reached approximately 1.2 m below ground level, a greater percentage of the recharge was released from the aquifer. As a consequence the closer the water table got to the land surface the greater the spring discharge was for a given water level rise (in well K37/2405). This is shown by the initial flow of water at site N2 which was 79 l/s when the water level in well K37/2405 was 1.26 m below ground level (after rising 2.3 m). Between November 2005 and April 2006 the groundwater level in well K37/2405 rose (consistently) 51 cm and the flow at N2 increased from 79 l/s to 415 l/s. Thus the water table rose more slowly because more water was released from the aquifer relative to the amount of recharge going in. This is why a considerable increase in the flow at N2 occurred with a relatively small rise in the groundwater level.

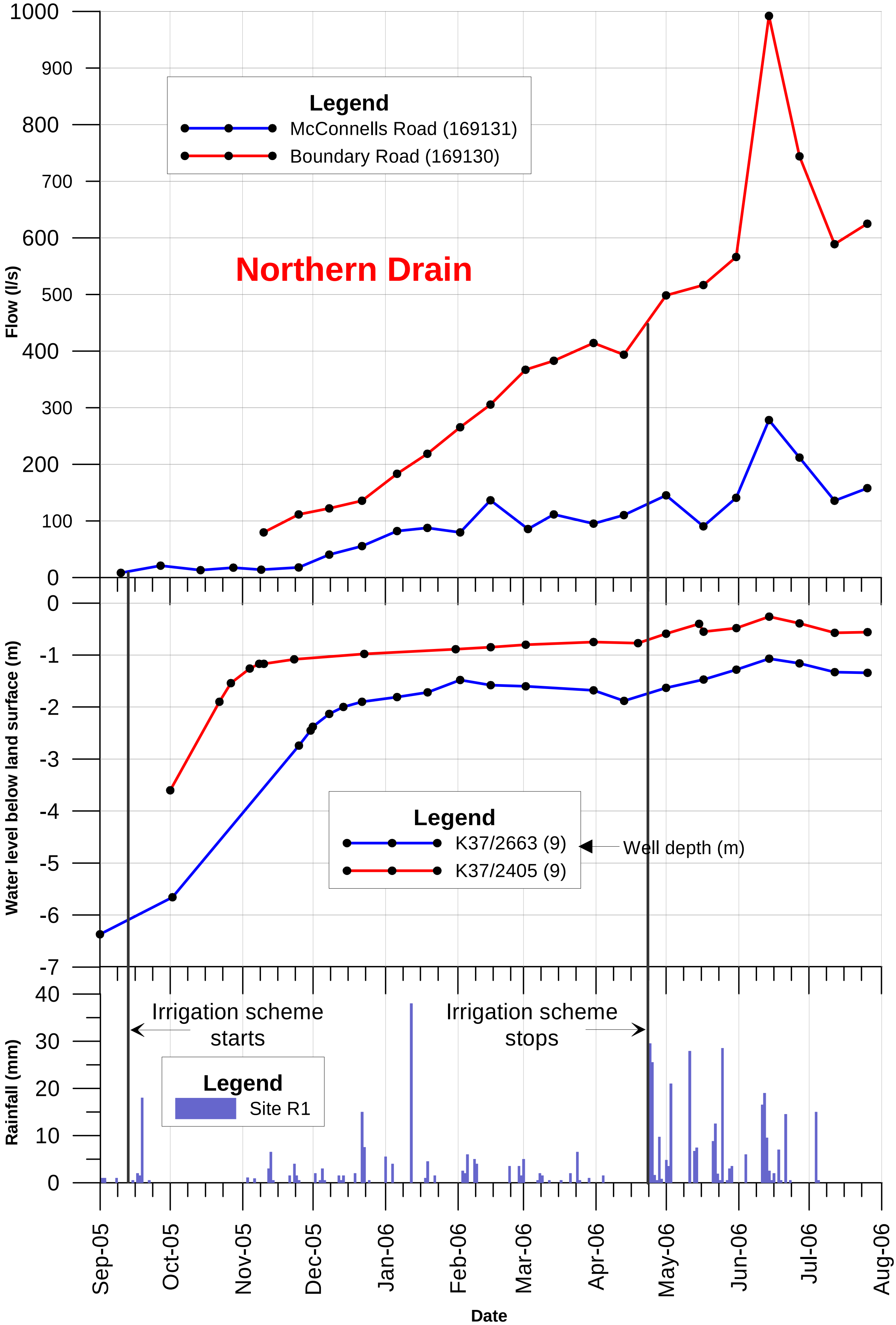

Figure 6.6 - Comparison of drain flow, groundwater levels and rainfall.

In contrast to the initiation of flow in Moffats Drain which started upstream and moved downstream, the Northern Drain first started flowing in its downstream reaches. As the groundwater table continued to rise the drain started flowing further upstream (Figure 6.7). This occurred because the depth to water table decreased from State-Highway 1 to Boundary Rd. This is shown by the shallower water level (as of September 2005) in well K37/2405 compared with well K37/0063, both wells are 900 m from the Hinds River (Figure 6.7).

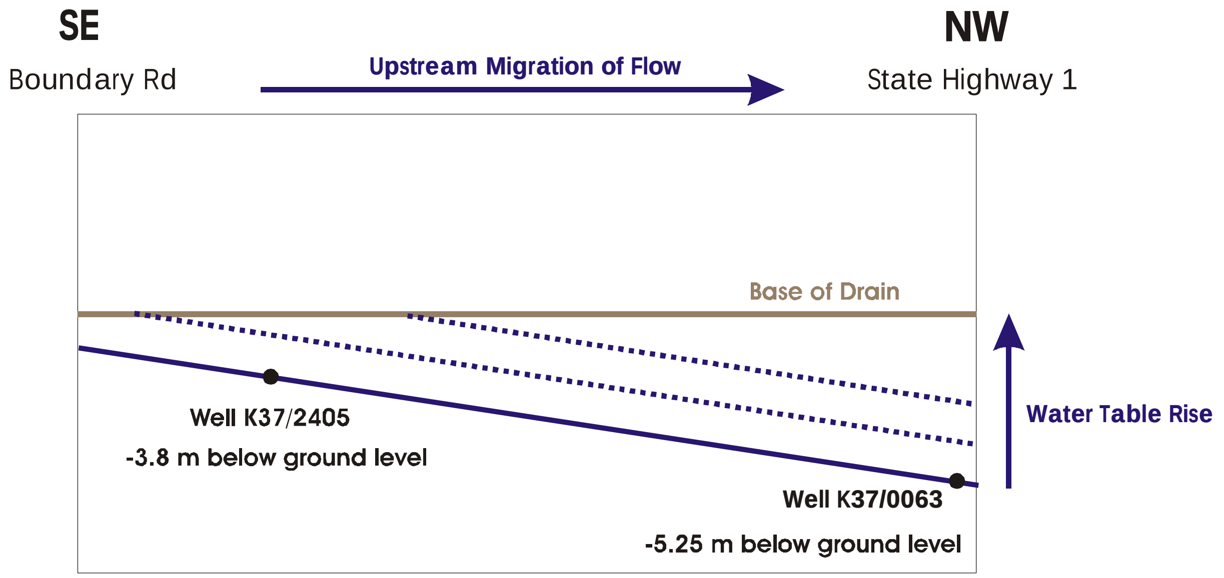

Figure 6.7 – Upstream migration of flow in response to a rising water table. Water levels for each well are at mid September 2005.

Figure 6.8 shows the gradual water level rise in well K37/2405 from November 2005 onwards, at which point the water table was high enough to produce a flow in the drain. In contrast well K37/0063 kept rising rapidly until February 2006, likely due to the prior depth to groundwater was greater. The slower gradual water level rise in well K37/0063 from February 2006 onwards suggests a significant increase in spring flow near State-Highway 1, as a consequence of a high water table intercepting the land surface. Evidence of significant spring flow from this area at this time is presented in Section 6.5.3.1.

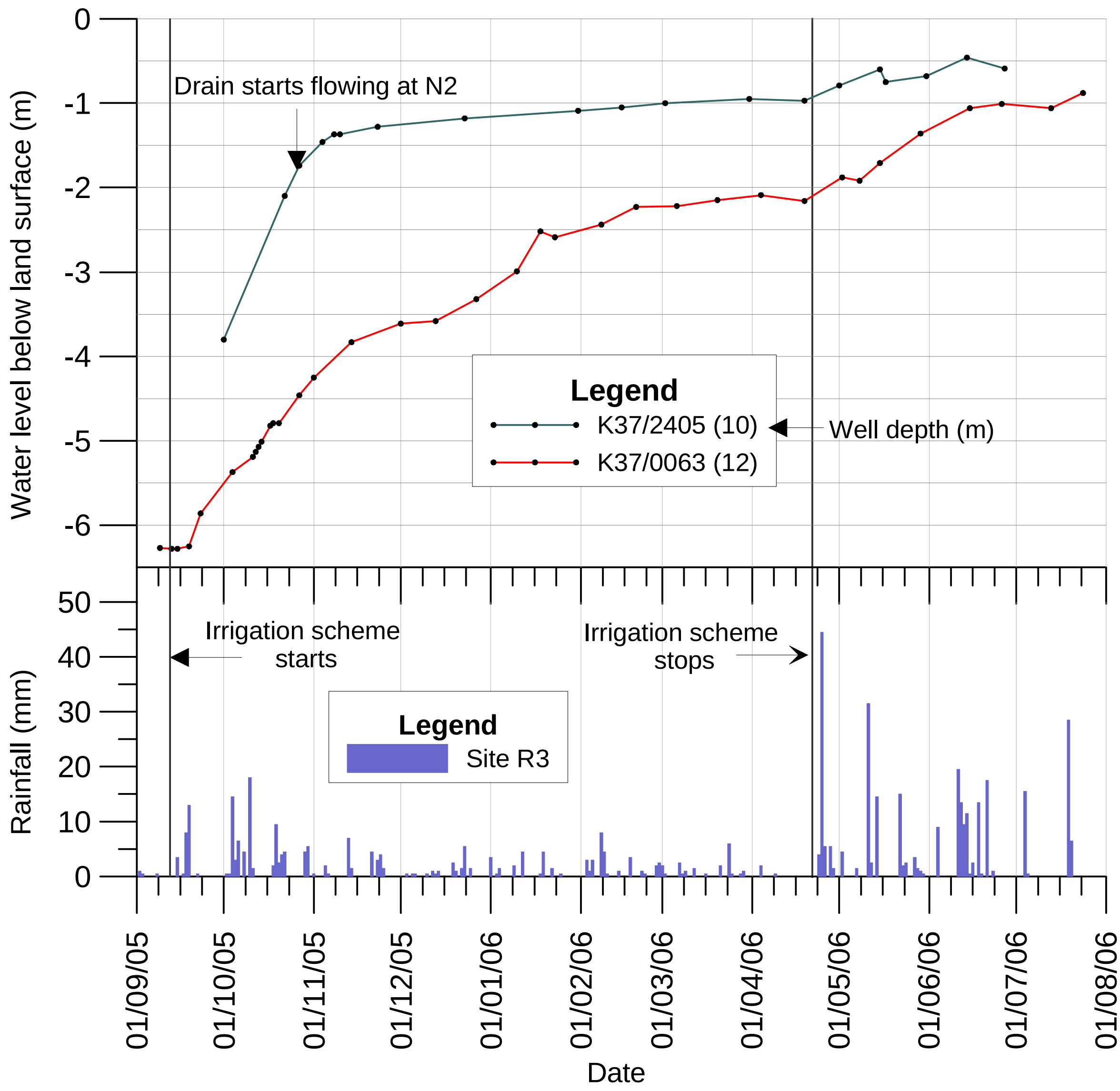

Figure 6.8 – Comparison of rising water table in response to spring flows.

In contrast to the flow at site N1, the flow at site N2 rose consistently throughout the entire irrigation season. This is shown by the consistent seasonal water level rise in well K37/2405 (close to N2) in contrast to the small mid summer water level decline in well K37/2663 (close to N1). The flow at N2 increased at a greater rate than N1 over the entire period of gauging. The increase in flow at N2 was greater than at N1 because N2 sourced water from a larger upstream area. The larger flow increase at N2 was also caused by the significant contribution from the shallow water table directly intercepting the drain, Bishops Drain and springs between Boundary Rd and McConnells Rd. In conclusion, the Northern Drain is highly affected by the Mayfield-Hinds scheme with significant increases in flow (approximately 400 l/s) occurring over the summer. In addition, heavy winter rainfall will also cause the water level to rise considerably.

Note that heavy summer rainfall would be offset by less border-dyke irrigation thus heavy winter rainfall is more likely to cause large flows.

6.3.4 Boundary Drain

Boundary Drain is 9 km long and starts near Isleworth Settlement Rd before merging with Moffats Drain and flowing into the ocean (Figure 6.3). The current consented take (from the drain) is 604 l/s and a number of abstractors take water upstream of the recorder site. A comparison of drain flow (between February 2004 and October 2006) with groundwater levels (in nearby wells) and rainfall (at the coast) is shown in Figure 6.9. Drain flow fluctuations show an influence from both scheme and rainfall recharge and rainfall runoff. The increased summer flow is most likely caused by a combination of inflow from Moffats Drain (flows increase over summer in response to border-dyke recharge) and from the two smaller tributary drains which also occur within the Mayfield-Hinds scheme. These feeder drains gain in flow each summer when groundwater levels rise. This summer is evident by the water level rise in nearby well K37/1791 (6 m deep). Note that the summer flow increase occurs despite upstream abstractions. Flow in the remaining sections of the drain which occur outside the scheme boundary will be more consistent and likely rise from December to June. This occurs because groundwater levels down-gradient and north east of the Mayfield-Hinds scheme experience smaller seasonal fluctuations and are predominantly rainfall recharged in contrast to groundwater within the scheme boundary. This is shown by the relatively small seasonal fluctuations in well K38/0097 (4 m deep). Drain flow also shows a large and rapid response to local rainfall events. Over winter 2006, sharp rises in flow of up to 5,500 l/s occurred in response to local rainfall events greater than 20 mm. The corresponding groundwater level rise would have contributed to the rise in flow, however the sharp rise and fall suggests that surface runoff can at times cause the greatest increase in flow.

6.3.5 Un-named Drain

Photos and groundwater levels were taken adjacent to a private un-named drain located between Coldstream and Boundary Rd (Figure 6.3). Upstream from the two photo sites groundwater inflow is sourced from depression springs and seepage from the banks and bed of the drain. Between September 2005 and February 2006 the water level in nearby well K37/1689 (9 m

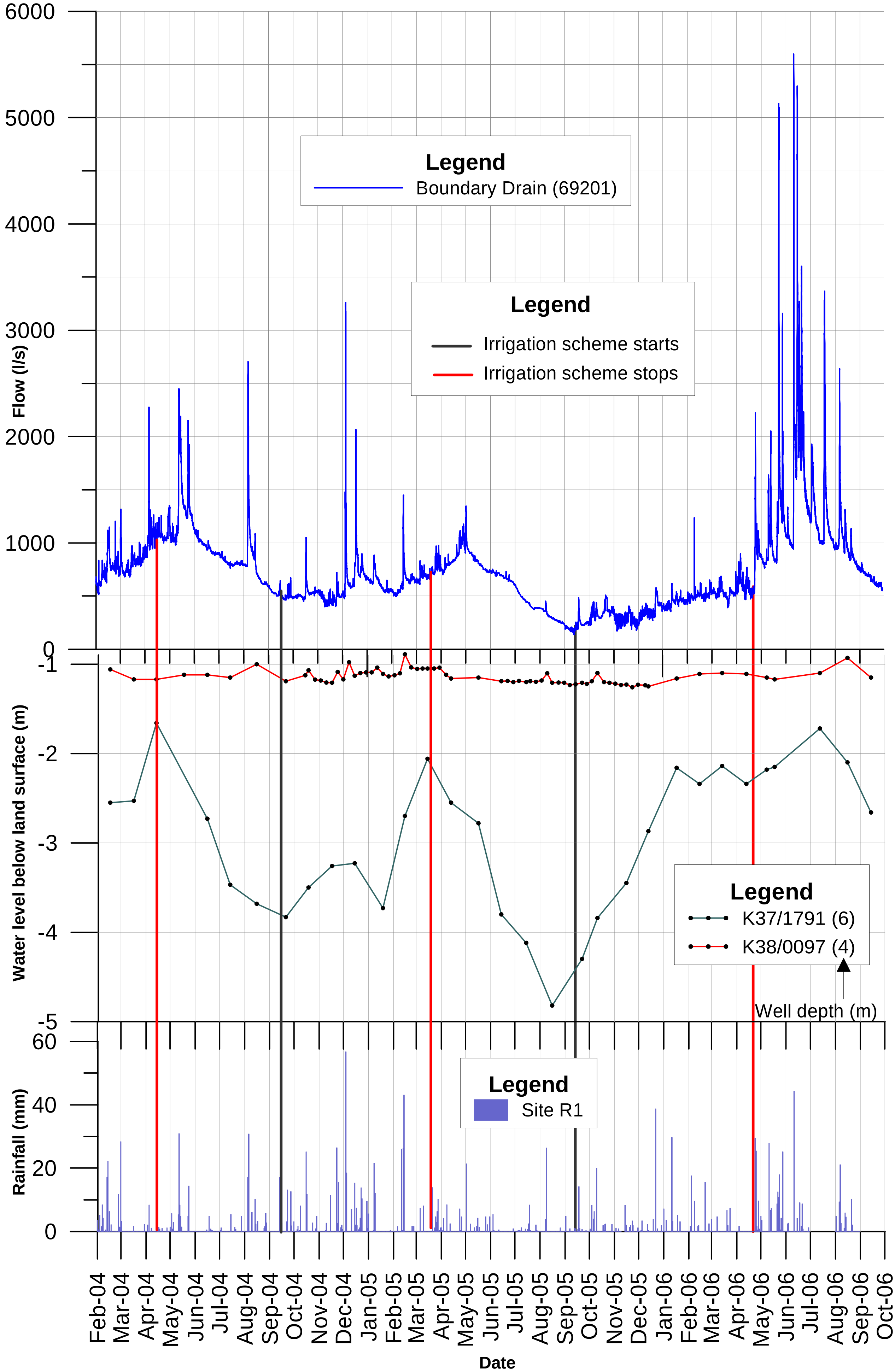

Figure 6.9 - Comparison of drain flow, groundwater levels and rainfall.

deep) rose from -5.0 to -1.2 m below ground level. In comparison, the un-named drain was dry between September 2005 and early February 2006, at which point a small flow occurred (Appendix 6.5). Thus the drain flow is highly affected by the Mayfield-Hinds scheme. Between late April and July 2006, heavy winter rainfall caused the water level in well K37/1689 to rise within 9 cm of the top of the casing. This high water table created a depression spring adjacent to the well (Appendix 6.5). Water from the spring followed the path of a natural gully before entering the un-named drain further downstream. Flow in the drain significantly increased during this period (Appendix 6.5). Groundwater level fluctuations and corresponding drain flow demonstrates the significant combined recharge effects from both the Mayfield-Hinds scheme and rainfall.

6.3.6 Oakdale Drain

Geomorphology and Hydrogeology

Oakdale Drain (Figure 6.3) is 4 km long and starts approximately 2 km upstream of Wrens Rd following the base of the upper Rangitata River Terrace (Photos F and G in Appendix 6.6) before seeping through a gravel barrier bar and into the ocean. At its source the drain is fed by a stockwater race (Photo A in Appendix 6.6) with an average flow of 15 l/s and at Wrens Rd another stockwater race (similar flow) flows into the drain. Upstream of the gauging site groundwater inflow is sourced from depression springs, terrace riser springs, tile drains and minor groundwater seepage from the banks and base of the drain (Appendix 6.6). Terrace riser springs occur where the water table intersects the terrace. Some terrace riser springs are associated with discrete permeable gravel lenses (Photos B, C and E in Appendix 6.6), similar to those described in Chapter 2.5.4. Depression springs occur within a small wetland area just north of Wrens Rd (Photo F, Appendix 6.6). Simultaneous gaugings in November 2005 showed a 22% increase in flow from the Wrens Rd gauging site (79 l/s) to a gauging site (90 l/s) 1 km downstream (Figure 6.3). This likely occurred from terrace riser spring flow further downstream.

Seasonal Fluctuations in Flow

Two weekly gaugings were taken from September 2005 to August 2006 (Figure 6.10). Drain flow closely followed the water level fluctuations in well K38/0006 (10 m deep) 55 m from the drain. Between September and December 2005 drain flow increased slightly from 64 l/s to 72 l/s, in comparison the groundwater level in well K38/0006 rose 20 cm. Over this period there was very little rain suggesting a small recharge influence from the Mayfield-Hinds scheme. Between January and April 2006 drain flow increased from 72 l/s to 102 l/s, in comparison the groundwater level in well K38/0006 rose 50 cm. The larger rise in flow and larger groundwater level rise coincide with large rainfall events in December 2005 and February 2006. Between March and April 2006, during which period there was less rainfall, both the flow and groundwater level remain relatively stable. Heavy rainfall between late April and August 2006 caused the flow to increase from 102 l/s to 283 l/s, in comparison the groundwater level in well K38/0006 rose 1.4 m. The relatively large rise in groundwater levels suggests that a higher groundwater level was the main reason for the increased flow, rather than surface runoff. Therefore it is likely that rainfall is the dominant source of groundwater recharge with a relatively minor recharge contribution from the Mayfield-Hinds scheme. Some presence of scheme recharge is also evident from a farmer who stated that the flow increases slightly over summer and is greater now than 20 years ago (cited in Davey, 2003).

6.3.7 Griggs Drain

Geomorphology and Hydrogeology

Griggs Drain is approximately 11 km long and starts at Bryants Rd before seeping through a gravel barrier bar and into the ocean (Figure 6.3). The drain is generally 1.5 – 2.0 m deep (deeper than most) and the flow is dominantly from tile drains (Appendix 6.7). Springs may feed this drain, however none have been mapped. The gauging site is approximately 50 m downstream from where the drain starts. Upstream of the gauging site the drain is fed by a large tile drain (reportedly one of the largest ever dug) which likely runs for 1 – 2 km parallel to the Hinds River. This tile drain is the dominant source of flow for the entire drain. In addition a smaller tile drain is present 10 m upstream of the gauging site.

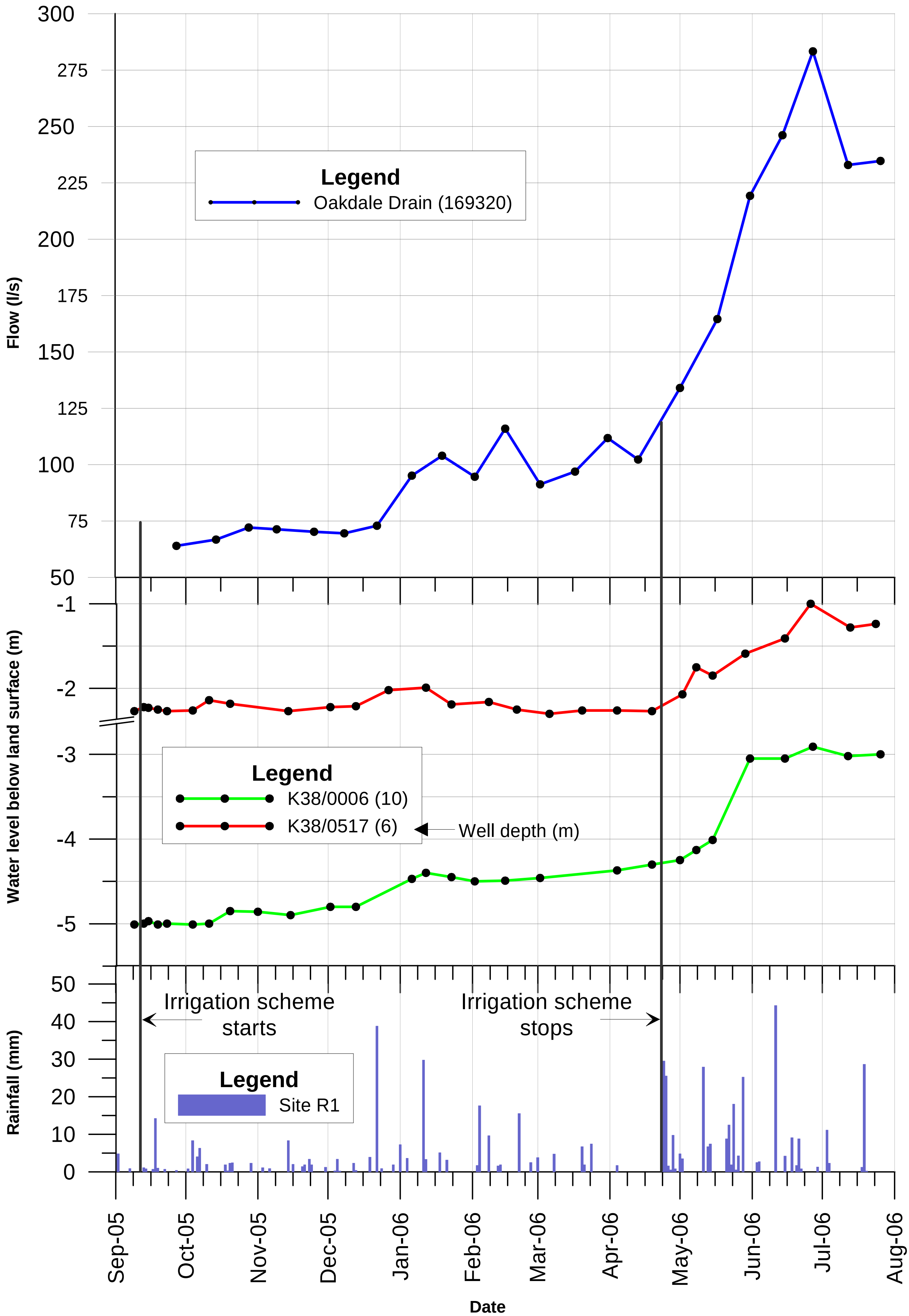

Figure 6.10 - Comparison of drain flow, groundwater levels and rainfall.

Seasonal Fluctuations in Flow

Two weekly gaugings were taken from September 2005 to August 2006 (Figure 6.11). Drain flow followed the same general pattern as water level fluctuations in nearby wells K38/0097 (4 m deep) and K38/0623 (9 m deep). This would be expected from a predominantly tile drain groundwater sourced flow. Groundwater levels and corresponding drain flows show a predominantly rainfall recharge influence with no effects from the Mayfield-Hinds scheme. Medium sized rainfall events (10 – 15 mm) in September and October 2005 produced a small rise in groundwater level and drain flow. An increase in drain flow between December 2005 and April 2006 corresponded with rainfall and a subsequent water level rise in well K38/0097. The peak flow in June 2006 corresponded with a 40 mm rainfall event and a sharp water level rise in well K38/0623.

6.3.8 Heddlee-Smythe Drain

Geomorphology and Hydrogeology

Heddlee-Smythe Drain is approximately 3.5 km long and starts adjacent to Brogdens Rd before flowing into the ocean (Figure 6.3). Upstream of the gauging site groundwater inflow is sourced from depression springs, tile drains and groundwater seepage from the banks and bed of the drain (Appendix 6.8). Photos of the drain and adjacent areas were taken in June 2006 after significant heavy rainfall. In many cases depression springs could not be distinguished from surface ponding, and these are labeled as such in Appendix 6.7. The water table at this time (as measured from nearby well K38/1048) was 50 cm below ground level thus many of the potential springs were likely to have been groundwater fed.

Seasonal Fluctuations in Flow

Two weekly gaugings were taken from September 2005 to August 2006 (Figure 6.12). Local farmers stated that surface runoff from up-gradient border-dyke paddocks occasionally increase the flow, however no affects of this were observed. Drain flow followed the same general pattern as the groundwater level fluctuations in nearby wells K38/0096 (8 m deep) and K38/0412 (9 m deep). Groundwater levels and corresponding drain flows show a dominantly rainfall recharge influence with no effects from the Mayfield-Hinds Irrigation scheme. A medium sized

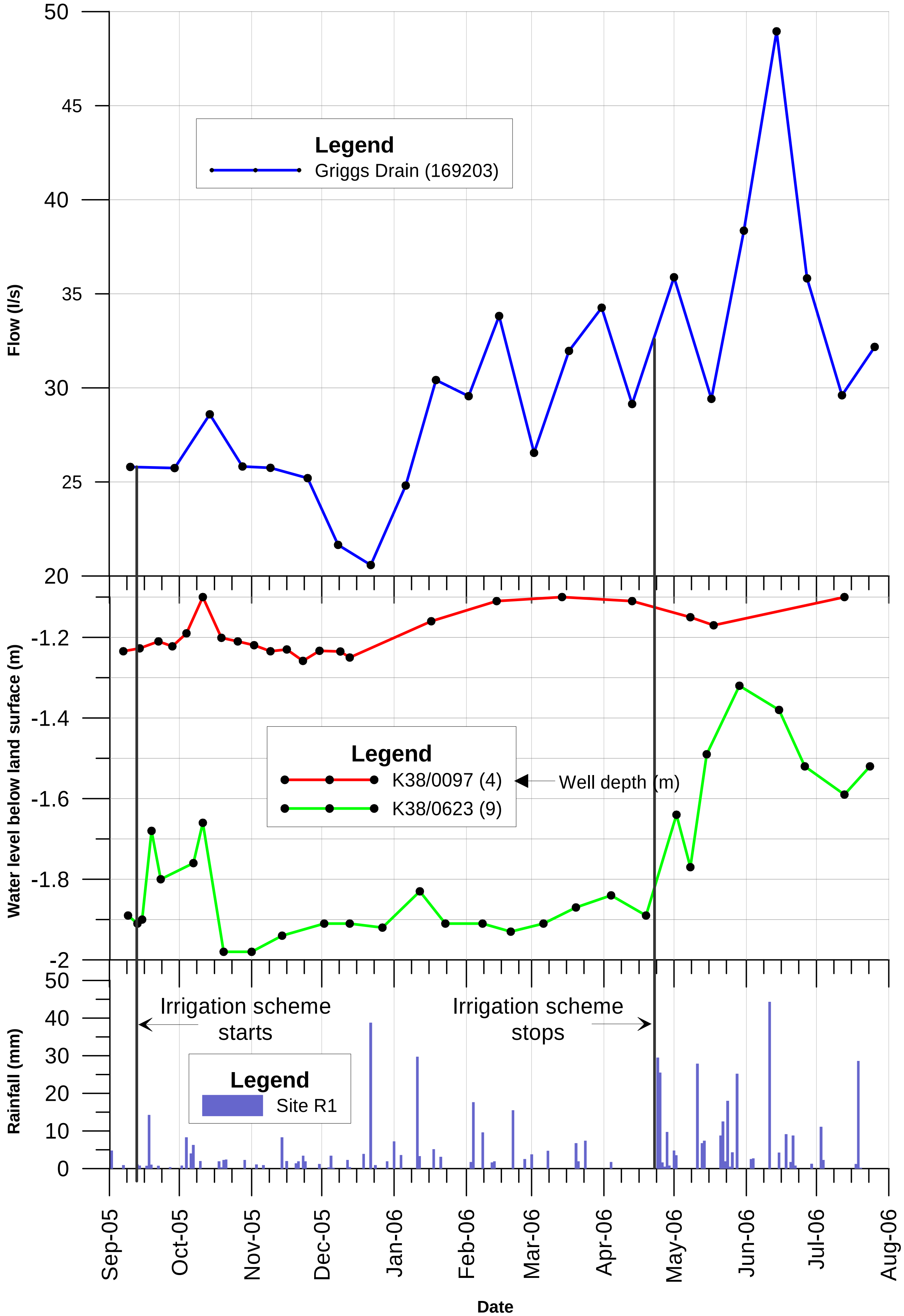

Figure 6.11 - Comparison of drain flow, groundwater levels and rainfall.

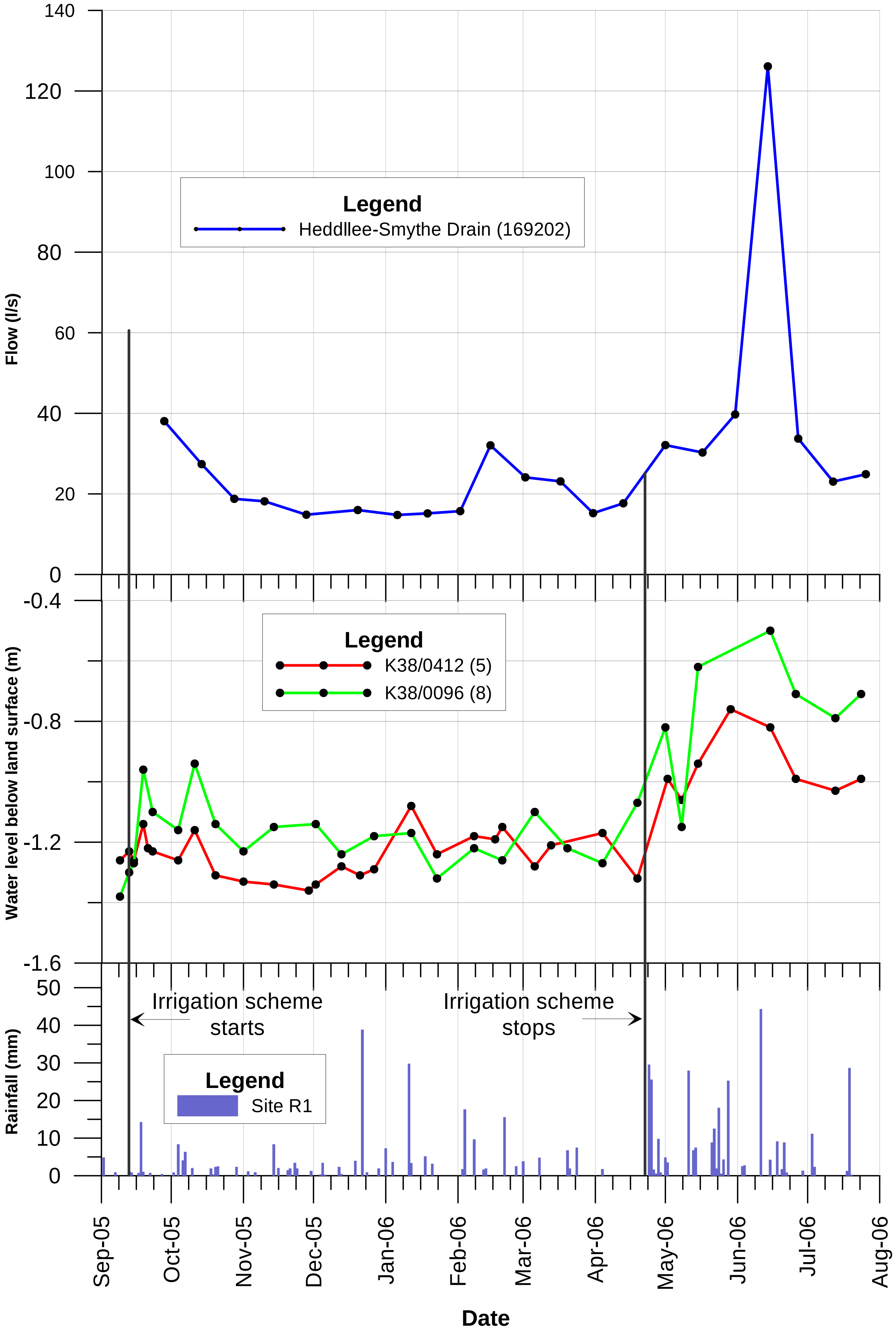

Figure 6.12 - Comparison of drain flow, groundwater levels and rainfall.

rainfall event (15 mm) in September 2005 produced a small rise in groundwater levels and drain flow. Over summer the flow remained relatively stable despite two large rainfall events. The peak flow in June 2006 corresponds with a 40 mm rainfall event and sharp water level rise in both wells.

6.3.9 Stormy Drain

Stormy Drain is approximately 4 km long and starts near Emersons Rd before flowing into the ocean. Upstream of the recorder site, groundwater inflow is known to be sourced from depression springs. No field work was conducted on this drain so its morphology is not described. The fluctuating flow over the irrigation season was largely due to surface abstraction, with 240 l/s taken every two weeks for border-dyke irrigation (Figure 6.13). Despite this surface take, it is likely that the flow remained relatively stable all summer, following the same general pattern as the groundwater levels in wells K38/0096 (8 m deep) and K38/0412 (9 m deep). In addition, most of the drain occurs within Zone 3, where groundwater levels show little or recharge effect from the scheme. Farmers in the area also stated that the highest flows occur between April and June (Dodson, 2006), this coincides with highest average monthly groundwater levels in this area. The sharp rise in both groundwater levels and flow in response to heavy winter rainfall suggest this drain is dominantly rainfall recharged.

6.3.10 Irrigation Laterals 4 and 5

When the water table is high, irrigation Laterals 4 and 5 act as drains by receiving a large inflow of groundwater from nearby springs and private drains (Appendix 6.9). The scheme raceman noted that the laterals receive a combined groundwater flow of approximately 200 l/s from December onwards. This water is used by the scheme and enables the racemen to allocate additional water. The groundwater inflow is likely caused by a rapid early season water table rise from border-dyke irrigation. According to the raceman, an area of significant groundwater inflow from springs occurs near the corner of Pyes Rd and Coldstream Rd. The location of springs that likely flow into these Laterals is shown in Appendix 6.9. In August 2006 after above average summer and winter recharge, photos were taken (Dodson pers, comm) of Lateral 4, Lateral 5 and of two un-named drains which flow into Lateral 4. The photos show considerable groundwater sourced flow in both un-named drains and in both irrigation Laterals.

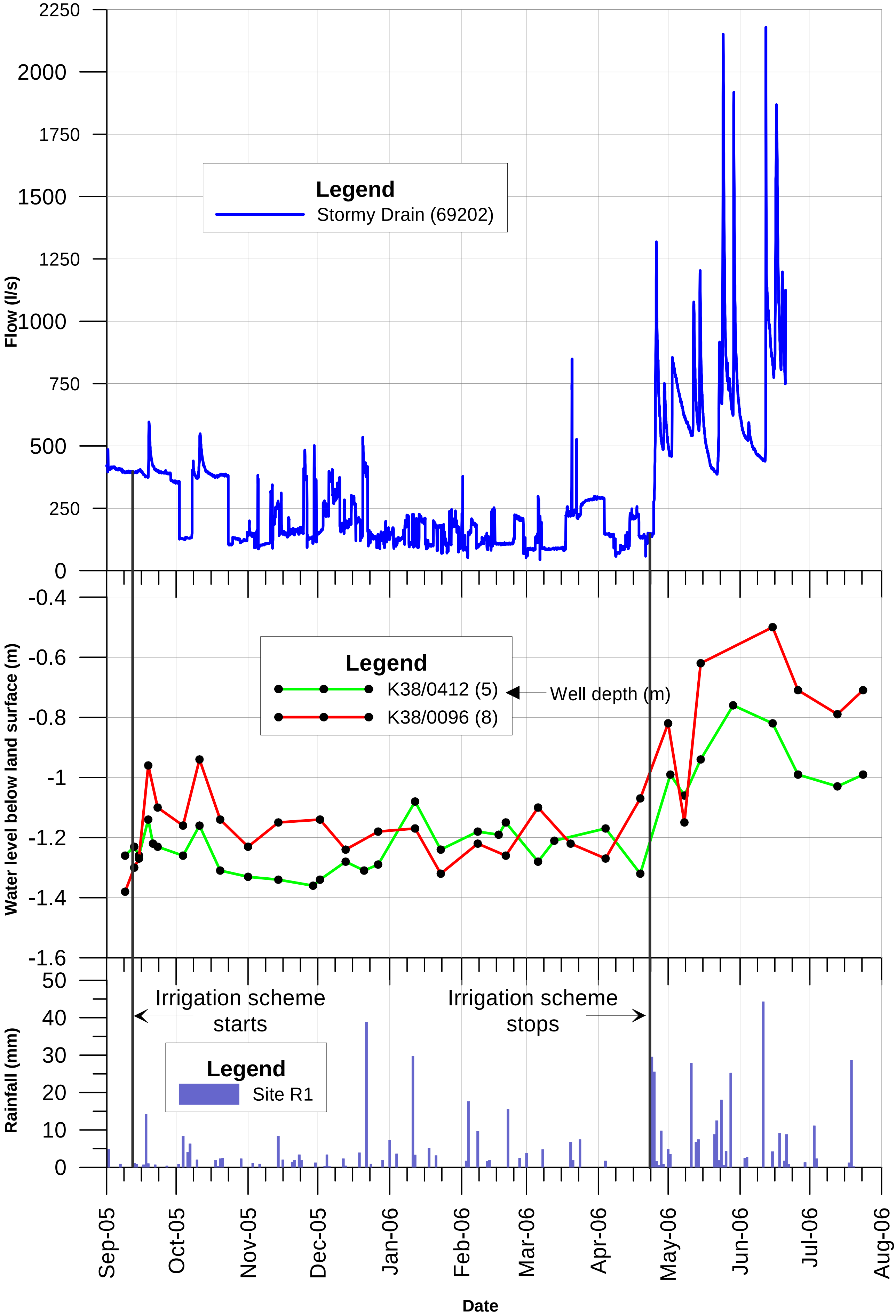

Figure 6.13 - Comparison of drain flow, groundwater levels and rainfall.

In addition, a large flow upstream of where un-named drain A flowed into Lateral 4 suggests that private spring-fed drains and gullies may contribute groundwater as far inland as Boundary Rd or State-Highway 1. The total groundwater sourced flow at this time was approximately 900 l/s. As a consequence of the very high water table at the time these photos were taken, it is likely that the groundwater sourced flow in these races was above average for this time of the year. Over the 2005/06 irrigation season groundwater inflow to Laterals 4 and 5 occurred from Late February, with a total flow of 290 l/s by Late April. As a consequence of the higher pre irrigation season water table (2006/07), the raceman estimated a groundwater inflow between 500 and 600 l/s over the duration of the 2006/07 irrigation season.

6.3.11 Discussion

The flow from drains that occur within, or partly within Zone 1 (zone boundaries presented in Figure 4.1 in the back pocket), show a general summer rise in response to increased groundwater levels and corresponding increased spring flow. Drain flows within Zone 3 are generally highest in mid winter and are dominantly affected by rainfall. In all cases drain flows are significantly increased by large local rainfall events. As part of a survey carried out in early 2006 (Dodson, 2006), farmers where asked what time of year they believed the drains on their property had the highest and lowest flows (Table 6.1) Within and just coastward Zone 1, most farmers believed that drain flows were highest from February to March. Within and just inland of Zone 3, most farmers believed that drain flows were highest in mid winter. These reports generally agree with the drain flow data collected in this study.

Table 6.1 – Qualitative data on the periods of high and low flows for some of the Hinds drains (Sourced from Dodson, 2006).

Drain	Highest Flow	Lowest (Flow)
Boundary Drain	Feb - March	Oct - Nov
Crows Drain	Similar all year	
Dobsons Drain	Winter	Feb
Fifty Link Drain	Aug - Sept	Feb
Harris Drain	Oct - March	
Moffats Drain	Dec - May	Aug - Oct
Montgomerys Drain	Dec	Aug
Northern Drain	Feb - March	Aug - Sept
Oakdale Drain	Feb - March	Oct
Pyes Drain	Feb - March	Oct
Stormy Drain	April - June	Nov - Dec
Twenty One Drain	Similar all year	

Key

(yellow box)	Drains that occur within the Mayfield-Hinds Irrigation scheme

6.4 Ealing Springs

Ealing Springs is a group of springs situated along the north bank of the Rangitata River, upstream of Ealing (Appendix 6.10). Most of the springs are depression springs emitted from the base of the main terrace riser or from ditches along or within a few meters of the terrace base (Davey, 2003). Nearby landowners believe these springs respond to both rainfall and scheme recharge (Davey, 2003). The main stream draining these springs is known as Ealing Springs Creek. The location of Ealings Springs Creek and three other streams (located in the field) are shown in Appendix 6.10. According to Fish and Game (2001) Ealing Springs Creek discharges between 400 and 800 l/s into the Rangitata River, just upstream of State-Highway 1.

Gauging of Ealing Springs Creek just upstream of State-Highway 1 was attempted in early March 2006. Due to impenetrable scrub this site could not be accessed. As a consequence, gaugings were taken on Ealing Springs Creek, a tributary stream and a stream draining a pond, all approximately 2 km upstream of where Ealing Springs Creek flows into the Rangitata River. The combined flow from Ealing Springs Creek and the tributary stream was 228 l/s, in addition 54 l/s was flowing from the pond near the base of the terrace. The lower flow in comparison to those reported by Fish and Game (2001) likely reflects the location of the gauging. Further downstream Ealing Springs Creek may gain considerably more water however this could not be determined as the end discharge point could not be accessed. The original purpose was to compare the flow between March and September 2006 in order to estimate what effect the Mayfield-Hinds scheme might have. A decreased winter flow from Ealing Springs Creek would suggest a border-dyke recharge effect as the groundwater level in border-dyke recharged aquifers (one and two) generally drops over winter. Due to a lack of time, no more gaugings were taken, however with the heavy winter rainfall it is likely that the flow increased over the winter.

6.5 Hinds River

On the same day that groundwater levels were taken, a record of whether the Hinds River was dry or flowing was made at 12 different observation sites (labeled S1 – S12) (Appendix 6.11) along the length of the river from just above Mayfield-Township to Poplar Rd near the coast. In addition the flow of bywash from Lateral 3 (Site B1) was also noted. Photos were taken every 2 weeks at sites S11 and S12 and at every other site when the river or bywash was flowing at that location (Appendix 6.12 a - m). A graph showing the periods of flow for all flow sites and springs, the groundwater level fluctuations adjacent to the river, Hinds River (south branch) flow and rainfall is provided in Appendix 6.13. This data was used to determine river losses and gains, recharge from irrigation bywash and the effects of river flow and irrigation recharge on spring flows within and adjacent to the bed of the Hinds River.

6.5.1 Water balance

Between the 16th and 17th of March 2006 the Hinds River was gauged at 8 sites from Mayfield Township to Lower Beach Rd (Figure 6.14). In addition, all surface water inflows to the river were gauged. This included 7 drains and Irrigation Lateral 3 (Figure 6.14). At the time of gauging there was no surface water abstraction from the Hinds River. Prior to the gaugings a total of 18 mm and 3 mm (at site R3) of rain fell during a one month and one week period respectively, with 0.5 mm of rain falling on the 16th of March. In addition, the Hinds River had been generally dry upstream from Boundary Rd to Mayfield Township for at least 12 months prior. Thus these results show a predominantly groundwater-sourced surface flow. Gaugings show the change in flow (Hinds River) with increasing distance downstream, losses and gains from the Hinds River and the contribution from drains and Lateral 3 (Table 6.2).

At H1 (gauged 20 m downstream of the Mayfield bridge) the Hinds River was flowing at 86 l/s. This flow was entirely sourced from Silver Stream Creek as both the Hinds River north and south branches were dry upstream of the Mayfield Bridge. The flow ceased at H2, 1.4 km downstream of H1, showing a loss of 86 l/s. This loss of water is evident by the groundwater level rise in well K37/2514 (550 m from the Hinds River) which occurs during periods of high river flow.

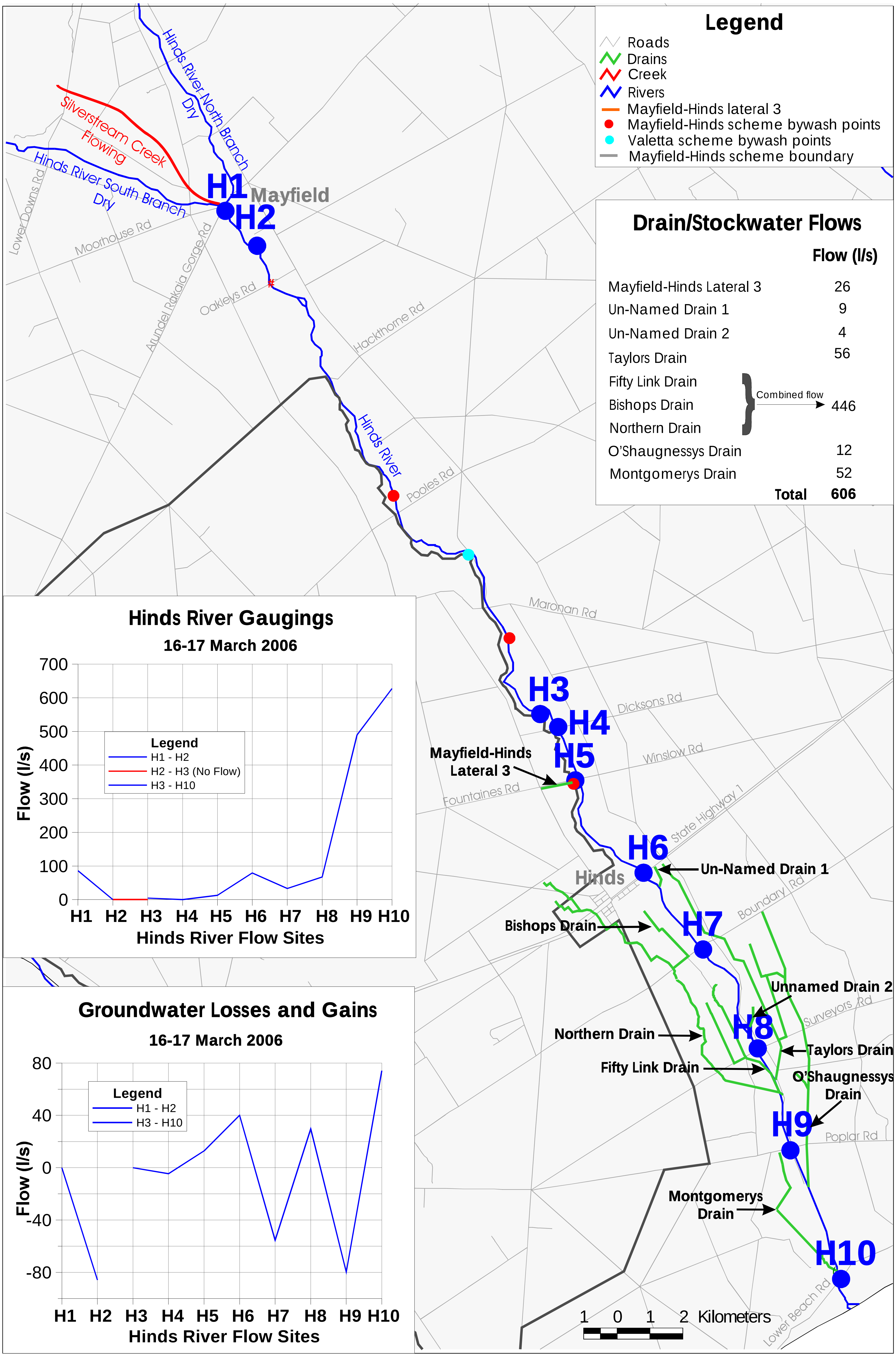

Figure 6.14 - Hinds River water balance showing Hinds River flow, surface water inflow and groundwater losses and gains.

Table 6.2 – Flow losses and gains along the Hinds River downstream from Mayfield-Bridge to the coast. Drain and race inflows and groundwater losses and gains are also shown.

Hinds River at	Flow (l/s)	Drains/Races	Flow (l/s)	GW Gains / Losses (l/s)
H1	86			**86**
H2	0			-86
H3	5			**5**
H4	0			-5
H5	13			+13
		Lateral 3	26	
H6	79			+40
		Un-Named Drain 1	9	
H7	33			-55
		Un-Named Drain 2	4	
H8	67			+30
		Taylors Drain	56	
		Northern, Bishops and Fifty Link Drains	446	
H9	490			-80
		O'Shaugnessys Drain	12	
		Montgomerys Drain	52	
H10	628			+74
		Total Input	**606**	

Downstream of H2 the Hinds River was dry until 700 m upstream of Dicksons Rd (H3) at which point water appeared flowing from a spring (K37/2723) within the bed of the river. This spring likely occurred as a result of the water table rise in response to Mayfield-Hinds scheme recharge. A small flow of 5 l/s was emitted from this spring before the flow ceased at approximately Dicksons Rd. Between H4 and H5 the Hinds River gained 13 l/s from the discharge of groundwater via springs within the bed of the river. 30 m below H5, 26 l/s from Irrigation Lateral 3 was released into the river. The water in Lateral 3 was likely derived from excess stockwater diverted into the race. Between H5 and H6 the flow increased from 13 – 76 l/s, of which 40 l/s came from additional spring inflow. The location of springs between H3 and H6 is shown in Figure 6.1. At H7 the total river flow (including 9 l/s from an un-named drain) was 33 l/s, showing a 55 l/s flow loss to groundwater. Landowners have long recognized this as a losing section of the river. In addition, no springs occur within this section (Figure 6.15) and when large quantities of bywash (from Lateral 3) were released into the river (Appendix 6.14), the flow quickly dropped downstream of H6 and never (over the course of this study) reached H7. Aquifer one piezometric contours (Figure 4.16) also show groundwater flow away from this section of the river. Bywash releases in October 2005 are the likely reason why the piezometric contours show a greater flow out from the river in November 2005. At H8 the total flow (including 4 l/s from an un-named drain) was 67 l/s, showing a 30 l/s flow gain from groundwater. The additional groundwater was likely picked up downstream of spring K37/2722 (Figure 6.14). A consistent flow of groundwater from this location was observed when the river upstream was dry. In addition, aquifer one piezometric contours show a slight groundwater flow towards this section of the river.

From H8 to H10 the Hinds River receives a considerable flow of water from drains. At H9 the total flow was 490 l/s. Between H8 and H9, 56 l/s from Taylors Drain and 446 l/s combined flow from Fifty-Link, Bishops and the Northern Drain entered the Hinds River. This suggests an 80 l/s floss loss to groundwater. At H10 the total river flow was 628 l/s. Between H9 and H10, 12 l/s from O'Shaugnessys Drain and 52 l/s from Montgomerys Drain entered the Hinds River. This suggests a flow gain from groundwater of 74 l/s. A total of 580 l/s entered the Hinds River from Drains (plus 26 l/s of stockwater) and at H10 the total river flow was 628 l/s.

Thus during dry periods when the Hinds River is predominantly groundwater-fed and not receiving water from foothills runoff (north and south branches dry upstream of Mayfield Township), drains and creeks account for the majority of the flow. In addition a relatively small contribution from springs within the bed of the river occurs when the adjacent water table is high. The importance of the scheme is highlighted by the fact that springs within the bed of the river (between H3 and H6) flowed as a result of the summer rise in groundwater levels. In addition, the combined flow from Bishops and the Northern Drain on the 14th of March was 382 l/s. As previously discussed, the combined flow from these two drains increased from 0 to 414 l/s over the summer irrigation season, in response to scheme recharge. Thus groundwater losses as a result of relatively inefficient border-dyke irrigation methods are significantly enhancing the flow of the Hinds River.

6.5.2 Effects of irrigation bywash

On the same day that groundwater levels were taken, a record was made of whether irrigation Lateral 3 (Site B1) was flowing and whether irrigation Lateral 1 water was flowing at site S5. A number of photos were also taken at each site (Figure 6.3). Water level fluctuations in well K37/0381 (13 m deep) 170 m from the Hinds River show no obvious peaks coinciding with bywash water flowing at S5 (Appendix 6.14). In contrast the water level in well K37/2259 (5 m deep) 350 m from the Hinds River near Hinds Township shows a sharp water level rise coinciding with a significant release of bywash from Lateral 3 in early October 2005. This rise would be expected as the Hinds River loses water between State-Highway 1 and Boundary Rd. The flow from this bywash event at sites B1 and S9 and the reduction in flow at each of these sites 3 days later at is shown in Appendix 5.14. Note that in all cases the flow of bywash extended no further than 700 m upstream of Boundary Rd. Appendix 6.14 also shows the behavior of river flow in response to a bywash release from Lateral 3 in Late October 2005. Near Winslow Rd only pools of water remained in hollows left behind after the flow of bywash had ended. In contrast there was a considerable flow of bywash water approximately 1.4 km downstream. This suggests that either the flow reduces downstream from the source (Lateral 3) after the flow has stopped, or that river underflow is forced to the surface at this location. River flow may be forced to the surface as a result of ironstone which is known to occur within the bed of the river near this location (refer to Chapter 2.5.6). Downstream of State-Highway 1 the flow of bywash visibly reduces.

6.5.3 Flow regime and sources of flow

6.5.3.1 August 2005 – April 2006

The following section outlines the flow regime and sources of flow in the Hinds River between August 2005 and April 2006. Despite the lack of foothills-sourced water, the Hinds River flowed over much of its length for varying periods of time in response to both groundwater level fluctuations and irrigation bywash. During this period of time, three distinctly different sections of the Hinds River were observed (Figure 6.15). A description of each section is provided below.

<u>Area 1</u>

The following discussion refers to Figure 6.15 and Appendix 6.15. Area 1 received a steady groundwater inflow from Silver Stream Creek, periodic inflow from foothills rainfall runoff and intermittent bywash from Lateral 1. Between August and September 2005 the Hinds River ceased flowing approximately 1 km downstream of site S2. The flow at S2 was totally derived from Silver Stream Creek. In early October 2005, foothills rainfall caused a significant flow in the Hinds south branch (S1) which enabled the river to extend approximately 1.5 km downstream of S4. By mid November (in the absence of significant rainfall) S1was dry and the flow had retreated to 50 m upstream of S4. In early November 2005 water was observed flowing

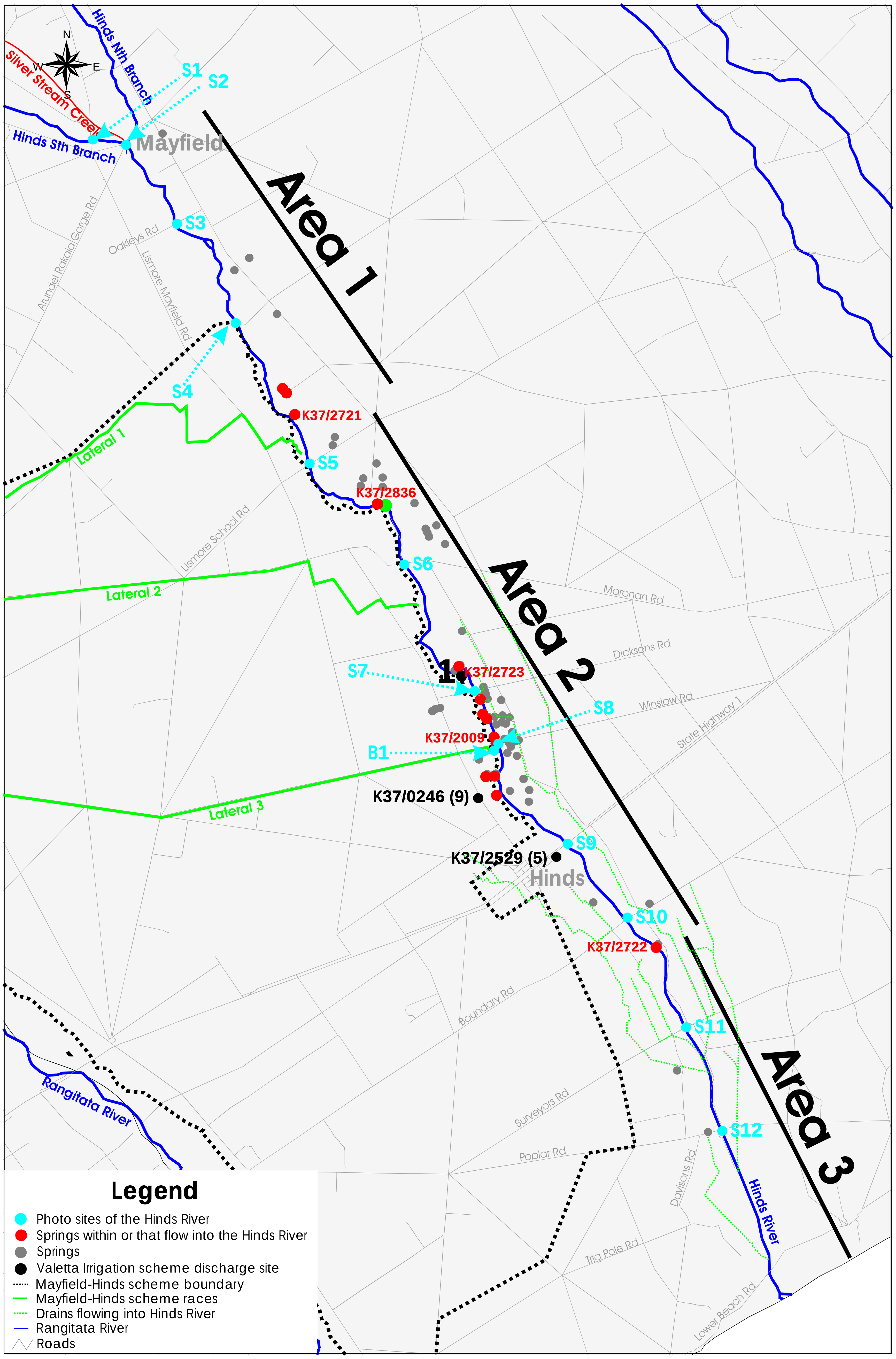

Figure 6.15 - Three distinctly different areas of flow regime during a dry period. The location of flow observation sites, springs, bywash discharge points and drains are also shown.

from a spring (K37/2721) within the bed of the river, 3.5 km downstream from where the Hinds River stopped flowing in early October. In early November water from this spring flowed to within 600 m of S5 before combining with bywash exiting Lateral 1. The combined flow of water extended 1 km downstream of S5. Spring K37/2721 possibly marked the location where river underflow intercepted the land surface. This spring was still flowing on the 1st of December 2005 at which point flow in the Hinds River had retreated further upstream to approximately S3. By the 27 of January 2006 the Hinds River had retreated to 500 m downstream of S2 and spring K37/2721 was dry. These observations suggest that the Hinds River causes groundwater levels within the bed of the river to rise for at least 2 – 3 km downstream of where the flow ceases. In addition, the continued flow from spring K37/2721 suggests that groundwater levels downstream of the river flow remain high for at least 2 months after the flow starts to declines.

Area 2

The following discussion refers to Figure 6.15 and Appendix 6.16. Area 2 was predominantly dry but flowed at specific locations from springs within and adjacent to the bed of the Hinds River and from Lateral 3 bywash. Springs flowed in response to both rainfall and Mayfield-Hinds scheme recharge. With the exception of bywash this section of the river was dry from August 2005 to mid January 2006.

In mid January sites S7, S8 and S9 started flowing from springs within the bed of the river. It is likely that the spring flow from S6 to S9 occurred as a result of both scheme and rainfall recharge. Wells K37/0246 (9 m deep) 600 m from the Hinds River and well K37/2529 (5 m deep) 300 m from the Hinds River occur between Hinds River sites S8 and S7 and showed a significant summer water level rise in response to Mayfield-Hinds scheme recharge (Appendix 5.13). In each well the water level rose from -6.9 to -2.4 m below ground level (K37/0246) and -4.7 to -1.9 m below ground level (K37/2529) respectively between mid September 2005 and early January 2006 (Appendix 5.13). On the 12th of January 2006, 41 mm of rain fell at site R3. On the 18th of January sites S7, S8 and S9 were observed flowing from groundwater feed springs within and adjacent to the bed of the river.

In late January, downstream from spring K37/2836 to spring K37/2723 water occurred in pools and in some cases flowed from depressions within the bed of the river. It is likely that the spring flow between S5 and S6 occurred as a result of rainfall recharge on top of a higher water table previously caused by the groundwater level rise downstream from where the Hinds River ceased flowing in mid October 2005 (refer to the discussion on Area 1 above). The effect of the Hinds River on the water table is shown by the high water level in well K37/0381 at S5 (shown in Appendix 6.13.). Between S5 and S6 the groundwater table intercepted the bed of the river for approximately 3 weeks as shown by the period of flow in spring K37/2836 (2.8 km downstream of S5). Spring K37/2836 may have flowed for a longer period of time however no earlier field observations had been made.

In contrast, spring flow caused sites S8, S9, and S10 to flow for the remaining duration of the study. Note the 3 week delay before a continual flow occurred at S10. Flow in the Hinds River slowly extended further downstream (from S9 to S10) as the groundwater table beneath the bed of the river was slowly filled with a combination border-dyke recharge and by the upstream flow of water in the Hinds River. By the mid February 2006, the Hinds River was flowing from 500 m upstream of S8 all the way to the coast.

Area 3

The following discussion refers to Figure 6.13 and Appendix 6.17. Area 3 flowed for the duration of the study. The river started flowing downstream of where groundwater discharged from the base of the south bank at spring K37/2722, 1.2 km downstream of Boundary Rd. Prior to creation of an artificial cut (completed in 1903) the Hinds River flowed into the Hinds Swamp half way between Boundary and Surveyors Rd. The flow downstream of spring K37/2722 likely occurs as a result of the artificial channel cutting beneath the high water associated with the Hinds Swamp. The point where water first started flowing remained unchanged for the duration of this study. In addition the flow at site S11 (Surveyors Rd) 2.7 km downstream of spring K37/2722, remained consistent from August 2005 before increasing slightly in February 2006. As previously discussed, the flow at Site 12 (Poplar Rd) was considerably greater than site S11 due to a large inflow from drains. Despite the large summer increase in flow from Bishops and the Northern Drain, two weekly photos suggest that the flow at S12 remained relatively consistent from August 2005 to February 2006, with a small increase in flow from February to April 2006. A number of factors may have contributed to the period of consistent flow. Firstly the combined consented abstraction from Fifty-Link and the Northern Drain is 356 l/s, thus abstraction from these drains would have limited the volume of water entering the Hinds River.

Secondly, overall groundwater levels adjacent to the Hinds River dropped between August 2005 and April 2006. Thus an increase in drain inflow may have been partly offset by a slight drop in the adjacent water table.

6.5.3.2 May – August 2006

Between April 23 and May 14, 112 mm of rain fell in the foothills at Klondyke (Environment Canterbury rainfall site 371210). This caused a significant flow of water in both the north and south branches of the Hinds River. A significant flow at sites S1 and S2 first occurred between the 8 and 15 of May. Approximately 10 days elapsed before the flow in the Hinds River moved downstream from S2 to S7. One landowner reported that the water took 3 – 4 days to move downstream from S5 to S6. The slow downstream migration of flow was likely caused by the relatively greater depth to groundwater between S2 and S7 prior to the heavy rainfall. For example near S2 the water level in well K37/2514 was 9.15 m below ground level and at S5 the water level in well K37/0381 was 13.2 m below ground level. Thus the water table could initially store a considerable quantity of the flow. By late May, the Hinds River was flowing for its entire length from Mayfield Township to the coast. This caused a significant rise in the adjacent water table.

6.6 Rangitata River

Past studies of the Rangitata River groundwater surface water interaction have looked at flow losses and gains and the effects of groundwater abstraction on river flows (Aitchison Earl, 2001). Flow losses and gains measured at different locations along the length of the Rangitata River downstream from the Rangitata Gorge (at Klondyke) have been estimated by Walsh (1975), Scarf and Waugh (1986) and Ingles (2000) (Appendices 6.18 a - b). Walsh (1975) and Ingles (2000) found a consistent flow throughout the length of the river and stated that small gains in flow occur downstream of State-Highway 1 when adjacent groundwater levels are high. Scarf and Waugh (1986) conclude that the river shows no obvious gaining or losing sections between Peel Forest and the Rangitata Mouth. Piezometric surveys were undertaken of the area north of the Rangitata in 1974 – 75 (South Canterbury Catchment Board, 1975) and the south of the Rangitata in 1975 (South Canterbury Catchment Board, 1975). These contours suggest that the Rangitata gains water from groundwater for most of its length. Piezometric contours drawn in this study show gaining and losing sections with significant changes in flow direction over time near Carew.

6.7 Distribution Race Losses

On the 10th of March 2006, gaugings were carried out on a Mayfield-Hinds scheme distribution race in order to determine the flow losses to groundwater (Table 6.3 and Figure 6.16). This distribution race was designed for a 10 cusec (283 l/s) flow. On the day of the gauging water was distributed 1.5 km from the turnout to a pond used for spray irrigation. To avoid the potentially large initial losses that may occur when the water is first taken, the race was left running for one hour prior gauging. In addition, the gaugings took place in the latter part of the irrigation season. This should have allowed the race to seal up slightly through the progressive deposition of silt over the summer. Gaugings were carried out on a cloudy day so evaporative losses were minor. Flow from the turnout was gauged three times throughout the gauging run in order to account for any variability. The inflow was shown to be consistent, considering the 8% margin of error associated with this method of gauging. Losses estimated from this site are less than the margin of error associated with gauging, thus the results are only an estimate.

Table 6.3 – Gauging results for an on farm irrigation distribution race.

Site	Distance from Turnout (m)	Time (24 hr)	Flow (l/s)	Loss (l/s)
1	5	1510 - 1545	292	
		1605 - 1640	300	
		1700 - 1740	294	
			295*	
2	495	1415 - 1445	294	-1
3	890	1510 - 1545	291	-3
4	940	1605 - 1640	288	-3
5	1540	1700 - 1740	272	-4
			Total Loss	**-11**

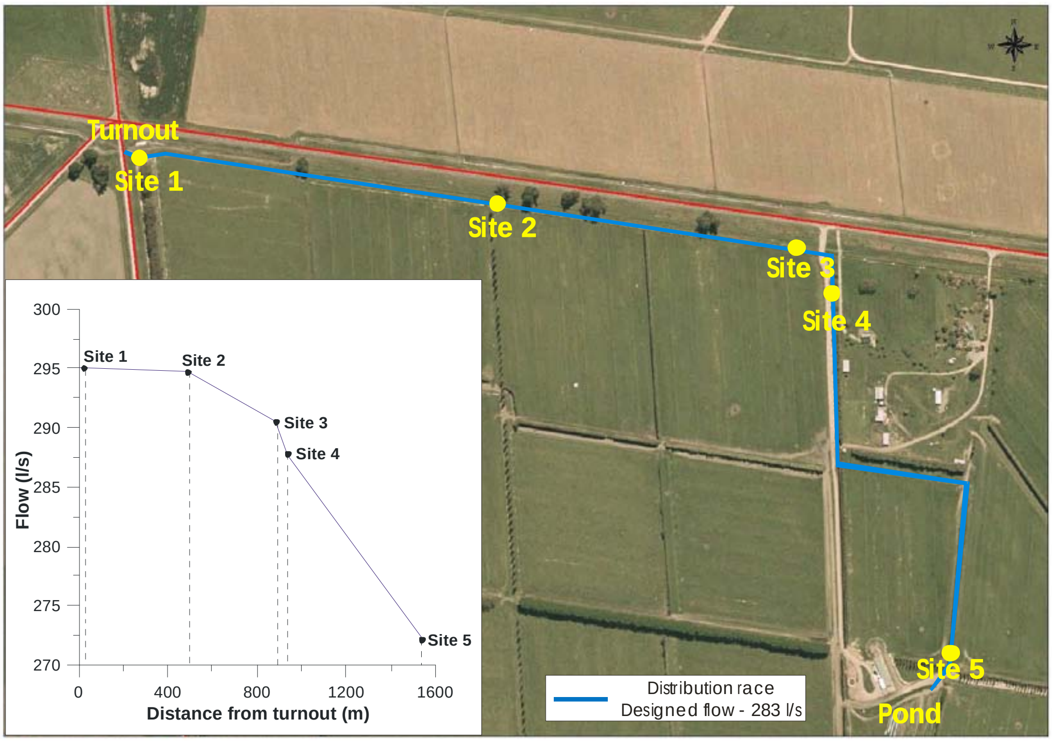

Figure 6.16 – Location of gauging sites and graph showing the flow losses downstream of the turnout.

Gaugings show a progressive overall loss of 11 l/s over 1.54 km and losses were greatest between sites 4 and 5. A small percentage of this loss (up to 1 l/s) occurred as a result of water spilling over headraces. This occurred from summer grass growth lifting up the water level. With data from only one gauging site the assumption that all distribution races within the scheme lose this much water is not possible. However the data does suggest that distribution race losses provide a significant amount of groundwater recharge.

6.8 Summary and Conclusions

6.8.1 Springs

The majority of springs within field area are depression springs, located between Coldtstream Rd and the Hinds Swamp. Those that occur within groundwater recharge Zone 1 (Figure 4.1 in the back pocket) are predominantly affected by border-dyke irrigation; in contrast those within Zone 3 are dominantly affected by rainfall. Many springs emitting from the Rangitata terrace are also highly affected by the Mayfield-Hinds scheme as are the depression springs within the Hinds River from Dicksons to State-Highway 1.

6.8.2 Drains

The flow in drains that occur within or partly within groundwater recharge Zone 1 show a general summer rise in response to increased groundwater levels. The flow in drains that occur within Zone 3 are generally highest in mid winter and are predominantly affected by rainfall. In all cases drain flows are significantly increased by rainfall.

6.8.3 Hinds River

Low Rainfall Periods

During dry periods both branches of the Hinds River are generally dry near Mayfield Township and a flow of water from Silver Stream Creek generally dries up within 1 – 2 km downstream of the Mayfield Bridge. From this point downstream to approximately Dickson Rd, the Hinds River is dry with the exception intermittent bywash releases and springs within the bed of the river that may flow in response to both Hinds River recharge and rainfall. Between Dicksons Rd and State-Highway 1, a summer groundwater level rise in response to Mayfield-Hinds scheme will cause springs to flow or increase in flow. Over time this flow may join with the flow of water downstream of Boundary Rd. This section is also highly affected by bywash released from Lateral 3. Halfway between Boundary and Surveyors Rd there is a consistent flow of water all the way to the coast. Between Surveyors and Poplar Rd the Hinds River gains a considerable flow of water from drains.

High Rainfall Periods

During wet periods the Hinds River will flow for its entire length as a result of foothills rainfall runoff. During periods of high flow a considerable amount of the surface flow is lost to groundwater.

6.8.4 Rangitata River

Unlike other major rivers such as the Rakaia and Ashburton, the Rangitata River shows no overall losses in flow. In addition, the river may gain in flow downstream of State-Highway 1 when adjacent groundwater levels are high. Piezometric contours also suggest little if any losses in flow, though this is likely dependent on the adjacent groundwater table.

6.8.5 Distribution races

Gaugings of a Mayfield-Hinds scheme distribution race suggest flow losses in the order of 7 l/s per kilometer. Due to an 8 percent margin of gauging error and the fact that only one race was accurately gauged, this flow loss may not be typical. However it is likely that losses from distribution races are an important source of groundwater recharge.

Chapter Seven

Regional Water Balance

7.1 Introduction

A regional water balance of the Hinds Rangitata Plain was carried out for a one period, between September 2005 and August 2006. For the purpose of this water balance, the Hinds Rangitata Plain is defined as the area between the Hinds and Rangitata Rivers, and from the coast, inland to the foothills near Klondyke (Figure 7.1). This water balance only looked at the groundwater system as a whole, thus the affects on separate aquifers is not yet known at this stage. Data collected during the course of this study was used to estimate the total contribution from each recharge and discharge component of the groundwater system. The one year period was broken into quarters, and the relative contribution from each component was totaled for each quarter. This provided an understating of how the ground and surface water system behaved over time. Over the one year period, the recharge and discharge components of the Hinds Rangitata Plain groundwater system, in order from most dominant to least dominant, are provided as follows:

Recharge components:

- Rainfall
- Mayfield-Hinds Irrigation Scheme:
  a) Irrigation recharge
  b) Race losses to groundwater
- Rangitata Diversion Race
- Hinds River

Discharge components:

- Drain flows
- Groundwater abstraction
- Rangitata River terrace springs

Components with no overall discharge or recharge:

- Rangitata River

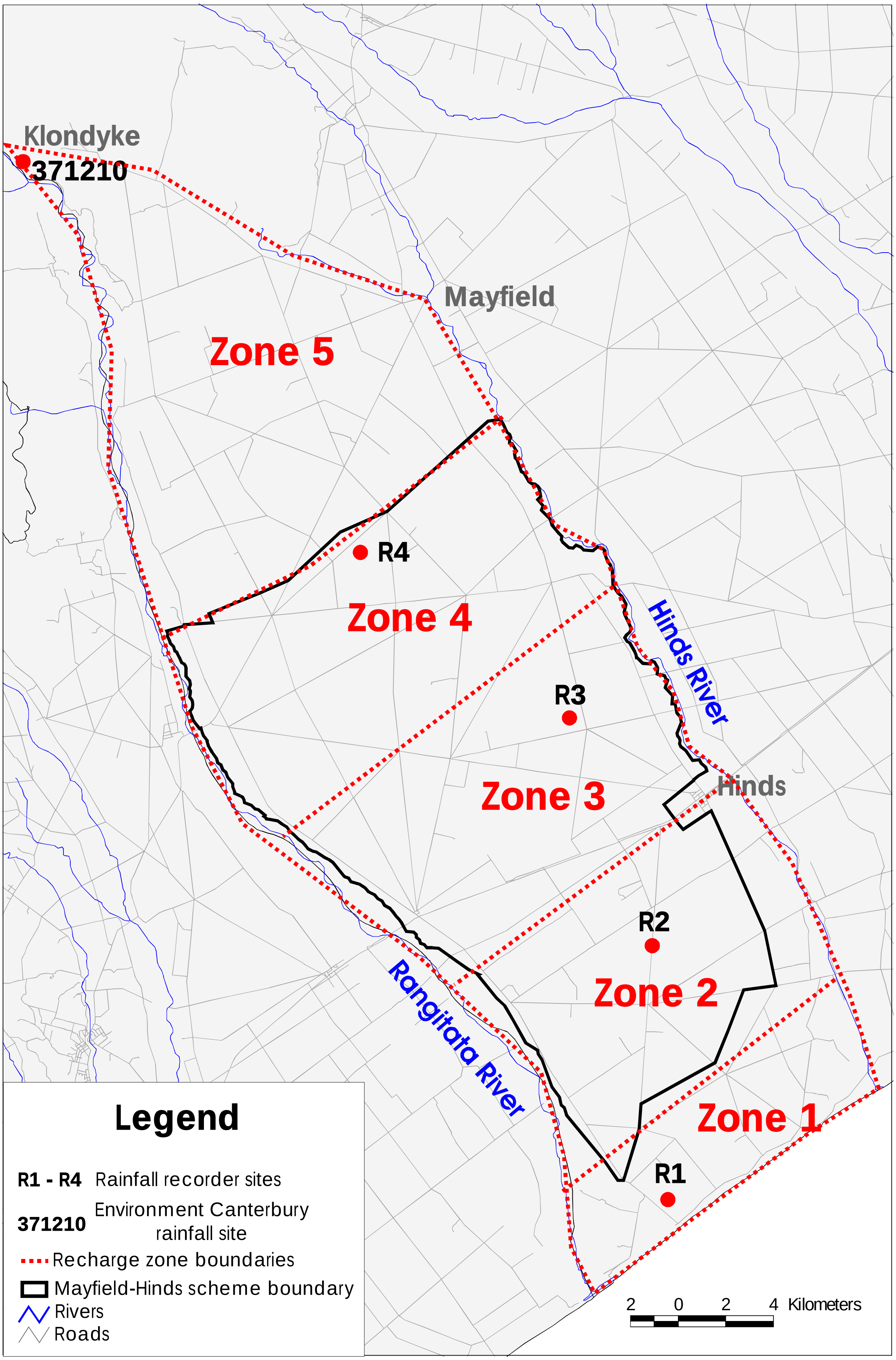

Figure 7.1 - Map showing the study area, Mayfield-Hinds Irrigation scheme and other features of interest.

- Stockwater Races

Sections 7.2 and 7.3 discuss the methodology behind the recharge estimates for each component. A discussion of the results is provided in Section 7.4.

7.2 Groundwater Recharge

7.2.1 Rainfall and spray irrigation recharge

Rainfall and spray irrigation recharge was estimated for five separate zones in order to account for the spatial variations in recharge during the one year period (Figure 7.1). Recharge was calculated using a soil moisture balance model developed by Scott, pers comm. (2006). Daily rainfall was collected from five rainfall recorder sites evenly spaced from the coast, inland to the foothills near Klondyke. Daily evapotranspiration data was taken from Winchmore Research Station, 25 km north east of the Hinds Rangitata Plain. This was the closest evapotranspiration site to the field area. With little variation in the rate of evapotranspiration over the Canterbury Plains, the data from this site should be highly representative of the field area.

Using the soil moisture model, groundwater recharge was calculated as the depth of water draining through the soil profile each day. The quantity of recharge from each zone was dependent on the profile available water (PAW, refer to Chapter 1.4.3), irrigation method, irrigation application depth, the total area (Table 7.1), rainfall and other parameters used in the soil moisture model. Irrigation events were restricted to occur from September to March.

Table 7.1 – Selected rainfall and irrigation recharge components for each of the five zones recharge zones shown in Figure 7.1

Recharge Components	Zone				
	1	2	3	4	5
Area ($m^2 \times 10^6$)	60	162	147	137	209
Profile Available water (mm)	110	65	55	55	65
Irrigation Method	Spray	Border-dyke	Border-dyke	Border-dyke	None
App. Depth (mm)	50	100	100	100	N/A
Return Period (days)	14	14	14	14	N/A

Daily drainage occurred when the rainfall, plus irrigation for selected zones, minus evaptranspiration, was greater than the total depth of water that could potentially be stored within the soil on that day. It was assumed that all excess water drained through the soil profile and recharged the groundwater system.

In Zone 1, recharge was equal to rainfall recharge, plus the recharge contribution from spray irrigation. Built into the model, an irrigation event of 50 mm was scheduled to occur once every 14 days (return period), but only when the PAW (refer to Chapter 1.4.3) fell below 50 % of the total PAW. Spray irrigation was given an application efficiency value of 80 %, meaning that groundwater recharge from an irrigation event was equal to 20% of the water applied. In addition, by simulating irrigation events, rainfall recharge was greater. This occurs because the soil moisture levels are kept closer to field capacity, thus when it rains, the soil is unable to store as much water. Any excess water above field capacity is assumed to drain from the soil to the groundwater.

In Zones 2 – 4, total recharge was equal to rainfall and the additional rainfall recharge which occurs as a consequence of irrigation keeping soils closer to field capacity. The majority of the area within these zones is irrigated from the Mayfield-Hinds Scheme. As a result, the drainage component from an irrigation event was not added to the total recharge, as recharge from the Mayfield-Hinds Scheme was calculated separately. Within Zones 2 – 4, an irrigation event of 100 mm was scheduled every two weeks, but only when soil moisture levels dropped to below 50 % of the total PAW. The recharge from rainfall plus irrigation was compared with the recharge under dryland conditions. The results showed that rainfall recharge under irrigated land was 16 % greater than from dryland.

In contrast to Zones 1 – 4, relatively little of Zone 5 is irrigated, thus the soil moisture model was run assuming that the area was dryland.

7.2.2 Irrigation race losses

Few detailed studies have been carried out on the distribution race losses within Canterbury irrigation schemes. An estimate of the race losses from the Mayfield-Hinds Scheme was based on studies by Duncan et al (1985), Bright et al (1987), trials carried out by the Mayfield-Hinds Irrigation Scheme, and the results from trials carried out during the course of this study. Duncan et al (1985) estimated 20 % flow losses from the on-farm distribution races, over the 1979/78 irrigation season, in the Valetta Irrigation Scheme. Bright et al (1987) estimated a distribution race efficiency between 47 % and 79 % for the Ashburton-Lyndhurst scheme over three irrigation seasons, between 1980 and 1984. Distribution efficiency was defined as the flow of water delivered to each farm (based on water sales data) divided by the inflow at the intake. This suggests that approximately 20 % of the water may be lost from the race network. During the 2003/04 irrigation season, trials were carried out by the racemen to estimate distribution races losses within the Mayfield-Hinds Scheme (Rouse pers comm., 2006). Results showed an average flow loss of 3 %. Flow loss gaugings were also carried out over the course of this study (refer to Chapter 6.7). Gaugings showed a 9 % loss in flow over a 1.5 km of headraces. With an absence of repeat gaugings, the margin of error associated with this method of gauging and data from only one gauging site, an assumption that all distribution races within the scheme lose this much water is not possible. However the data does suggest that distribution race losses provide a significant amount of groundwater recharge. Based on the improvements made in sealing these races over the past 20 years it is unlikely that average race losses are 20 % (as shown by previous studies). Based on more recent data, an average loss flow loss of 8 % was chosen for this water balance.

Groundwater recharge from the races was calculated as 8 % of the total daily flow taken at the intake, after first subtracting the losses via evaporation and from bywash. Evaporative losses were based on the average daily evaporation which occurs each month. The average monthly evaporation was taken from pan evaporation data, collected at Winchmore Research Station between 1950 and 1976 (Ministry of Agriculture and Fisheries, 1978). The volume of water evaporated from the races was estimated as the average daily evaporation (mm) times the average surface area of flowing water. The total surface area of the races is 2,400 km^2. However not all of the races flow 100 % of the time. The small delivery races and the on-farm distribution races flow for 75 % and 20 % of the time respectively (Rouse pers comm., 2006). Thus 75 % and 20 % of the total area covered by small delivery races and on-farm distribution races was assumed to have water flowing all of the time. As a consequence, average daily evaporation was estimated from a smaller surface area of 1,500 km^2, assumed to be exposed each day for the entire irrigation period.

No data was available on the quantity of irrigation bywash lost each season. However, the scheme raceman estimated that bywash over the 2005/06 irrigation season accounted for 3.5 %

of the total flow taken at the intake. This was then broken into a daily average volume and subtracted from the total daily flow taken at the intake.

7.2.3 Mayfield-Hinds Scheme, irrigation recharge

An estimate of border-dyke and spray irrigation recharge from the Mayfield Hinds scheme was based on the work of previous studies. Theses studies looked at the border-dyke and spray Application Efficiencies (AE) at a number of different sites around Canterbury. AE is defined as the total depth (mm) of water stored within the crop root zone (generally 700 mm depth), divided by the average depth (mm) of irrigation water applied. The water not stored within the crop root zone is assumed to recharge groundwater. A brief discussion of the range of AE values observed from different studies is provided below.

1) Duncan et al, (1985) looked at the AE for pre 1990, contour style borders within the Valletta Irrigation scheme (over the 1979/78 season) located between the Hinds and Ashburton Rivers. Results showed an average border-dyke AE of 26 %. The low AE value was caused by the low soil water holding capacity (45 mm avg), high application rates (170 mm avg) and inherent inefficiencies in the older style border-dyke systems.

2) Evans (1999) looked at AE within the Northbank Irrigation scheme near the Rakaia River. Results showed a maximum AE of 13 % for a contour style border-dyke, and 61 % for a rotating boom spray irrigator. The low AE value was partly due to the low soil water holding capacity (25 mm avg). In addition, inherent inefficiencies in the contour border-dyke systems and the high average application depth of 186 mm (in contrast to the average border-dyke application depth of 100 mm) also contributed to the lower border-dyke AE.

3) Stronge (2001) looked at the AE for contour borders over 262 border-dyke irrigation events at various locations within the Canterbury region. The results showed an average AE of 50 % for a typical 200 m long and 12 m wide border strip within a border group.

4) Lincoln Environmental (2002) looked at AE within the Ashburton-Lyndhurst Irrigation scheme (over the 1999/00 and 2000/01 irrigation seasons), located between the Ashburton and Rakaia Rivers. Results show the highest AE values under spray (67 – 85

%), lower values under laser leveled borders (48 – 62 %) and the lowest values under contour borders (44 %). The relatively high AE's in comparison to the previous studies, were partly caused by the higher soil water holding capacity (95 mm avg) in this area.

Based on the results of previous studies, and significant improvements made in the AE within the Mayfield-Hinds Scheme over the last 10 years (refer to Dodson, 2006), the following AE values were assigned. Old style contour borders (45%), new style borders (60%) and spray (80%).

Groundwater recharge from the scheme was then calculated from the flow taken at the intake after subtracting evaporative losses, bywash and race losses to groundwater. Each day, a percentage of the remaining flow (as determined after subtracting the above losses) was then proportioned to the old style contour borders (54%), new style borders (22%) and spray (24%). It was assumed that the percentage of the total area irrigated from the scheme equated to the same percentage of the volume of water used by each irrigation method. Thus because 54 % of the total area was irrigated in old contour style borders, 54 % of the flow left over was apportioned to this irrigation method. The final step was to apply the AE value as defined above for each of the irrigation methods. A final water balance summary for the Mayfield-Hinds Scheme is provided in Table 7.2.

Table 7.2 – Water balance for the Mayfield-Hinds Irrigation Scheme over the 2005/06 irrigation season.

Components	Volume (m^3 X 10^6)
Evaporative Losses	1
Bywash Losses	9
Race Losses to Gw	7
Irrigation Recharge	
- Contour Borders	71
- Wide Laser Borders	22
- Spray	11
Total Recharge	**111**
Total Volume Taken	**250**

7.2.4 Rangitata Diversion Race

The most recent flow gaugings of the RDR estimated an average flow loss of 20.4 l/s/km over the entire length of the main race (Young, 2003). This equates to an overall system loss of 346 l/s over the approximately 17 km's of race which cross between the Hinds and Rangitata Rivers.

7.2.5 Hinds River

Gaugings carried out over the course of this study showed little or no overall losses in flow from the Hinds River, downstream from S9 to the coast (Figure 4.1 in the back pocket). However significant losses in flow were observed between S2 and S9. Recharge from the Hinds River was based on the average monthly flow at site S2 as estimated (visually) from photos taken every two weeks (Appendix 6.12). Between September 2005 and April 2006 the entire flow of the Hinds River downstream of S2 was lost to groundwater before reaching S5. Thus over this period, groundwater recharge from the Hinds River was assumed to equal the entire flow at S2. The total recharge was then halved, assuming that half the recharge occurred north of the Hinds River and the other half occurred south of the river. During May 2006, the flow at S2 increased significantly. During this month the flow of water moved progressively downstream and by the late May 2006, the flow from S2 had joined to the flow of water further downstream at S8. Because of the low water table prior to May 2006, and the time taken the water to move downstream, the entire flow over May 2006 was assumed to have recharged the groundwater. Between June and August 2006 the Hind River flowed for its entire length. No gaugings have been carried out to assess the losses from S2 downstream to S9 as this section of the river was dry at the time of the gauging run carried out in March 2006. The general deepening of the water table from the Hinds River towards the Rangitata River suggests that the river would continue to lose water after the water table rose adjacent to the river. Thus river losses to groundwater between June and August 2006 were assumed to be 20% of the total flow observed at S2. This total was then halved, to account for recharge losses either side of the river.

7.2.5 Rangitata River

Unlike other major rivers such as the Rakaia and Ashburton, the Rangitata River shows no overall flow losses or gains (refer to Chapter 6.6). Thus no Rangitata River recharge is included in the water balance.

7.2.6 Stockwater Races

Little or no losses to groundwater occur from stockwater races because of the high silt content in the Rangitata River water which seals the races (Mowatt, per comm., 2006). Minor losses only occur upstream of State-Highway 1 where the water table is deeper. Downstream of State-Highway 1, the flow in most stockwater races is increased from spring inflow. Twelve stockwater races flow into drains near the coast and one flows directly into the ocean. Because very little if any water is lost from the stockwater races, groundwater recharge from stockwater races was not included as part of this water balance.

7.3 Groundwater Discharge

7.3.1 Groundwater abstraction

An estimate of groundwater abstraction was based on a first order groundwater allocation policy developed by Environment Canterbury (Aitcheson-Earl, 2004). Groundwater abstraction for each in use irrigation well, was calculated as the consented volume divided by the number of days (over which time that volume could be taken), times 150 days pumping (during the irrigation season), times 60 % (percentage of consented rate). The volume of abstraction for all currently used irrigation wells was totaled to give an estimate of the total seasonal groundwater abstraction. The total volume was proportioned relative to the number of irrigation days within each time period.

7.3.2 Groundwater and spring discharge

Groundwater from the Hinds Rangitata Plain is discharged via drains (dominantly from the Hinds Drainage Network), groundwater inflow to Laterals 4 and 5, Ealing Springs Creek, Rangitata River terrace riser springs and springs within the bed of the Hinds River.

<u>Drains, Laterals and Ealing Springs Creek</u>

There are 15 drains that discharge groundwater into the ocean, 3 that discharge into the Hinds River and one that discharges water into Lateral 4. In addition, Irrigation Laterals 4 and 5 act as drains when the water table is high and a large spring fed creek discharges water into the Rangitata River (Figure 7.2). Six drains had two weekly or less flow data, and visual flow observations were made from an unnamed drain and Laterals 4 and 5 over the course of this study (Table 7.3). The flow in nine additional drains (all within the Hinds Drainage Network) was recorded once in December 2005 and once in December 2006. The remaining four drains had no flow data, so the range of flows and average flow from these drains was based on landowner observations. The change in drain flow from drains with 2 weekly data or less was extrapolated out to estimate the change in flow from drains without periodic readings. For example, assuming the flow in Griggs Drain rose by 20 percent over one time period, the flow in nearby Montgomerys Drain was assumed to increase by the same percentage over the same time period. The changes in flow over time are provided in Table 7.3. The location of drains listed in Table 7.3 are provided in Figure 7.2.

Table 7.3 – Changes in drain flows over time. The Zones are the those defined in Chapters 4 and 5. Refer to Figure 7.2 for the location of the drains listed in the table.

Zone	Key (Fig 7.2)	Drain	Time Period - flow in l/s			
			1	2	3	4
1	B	Northern Drain (at Boundary Rd)	56	205	448	692
	F	Boundary Drain (Trigpole Rd)	253	416	754	1265
	T	Oakdale	83	104	155	294
	U	Un-named (O'Sullivans Drain)	0	10	50	100
	V	Laterals 4 and 5	0	100	500	800
	W	Ealing Springs Creek	240	300	450	855
		Total	**632**	**835**	**2357**	**4006**
3	A	Fifty-Link	38	40	48	56
	C	Montgomerys Drain	43	45	52	60
	D	Griggs (Bryants Rd)	26	27	32	37
	E	Morrows Drain	25	26	31	37
	G	Dobsons Drain	260	271	322	374
	H	Twenty One Drain	132	137	163	189
	I	Pyes Drain	79	66	90	163
	J	Maddisons Drain	6	5	7	13
	K	Heddlee-Smythe Drain	23	19	26	47
	L	Stormy Drain	282	167	374	742
	M	Un-named Drain 1	23	19	26	47
	N	McKeages Drain	69	57	78	141
	O	Un-named Drain 2	23	19	26	47
	P	Crows Drain	447	268	600	1,188
	Q	Yeatmans Drain	23	28	63	120
	R	Harris Drain	86	107	159	302
	S	Terrace Race	74	77	91	106
		Total	**1659**	**1378**	**2188**	**3669**
		Total - Zone 1 & 2	**2291**	**2213**	**4545**	**7675**
		Total - Zone 1 & 2 (m^3)	**18**	**17**	**36**	**61**

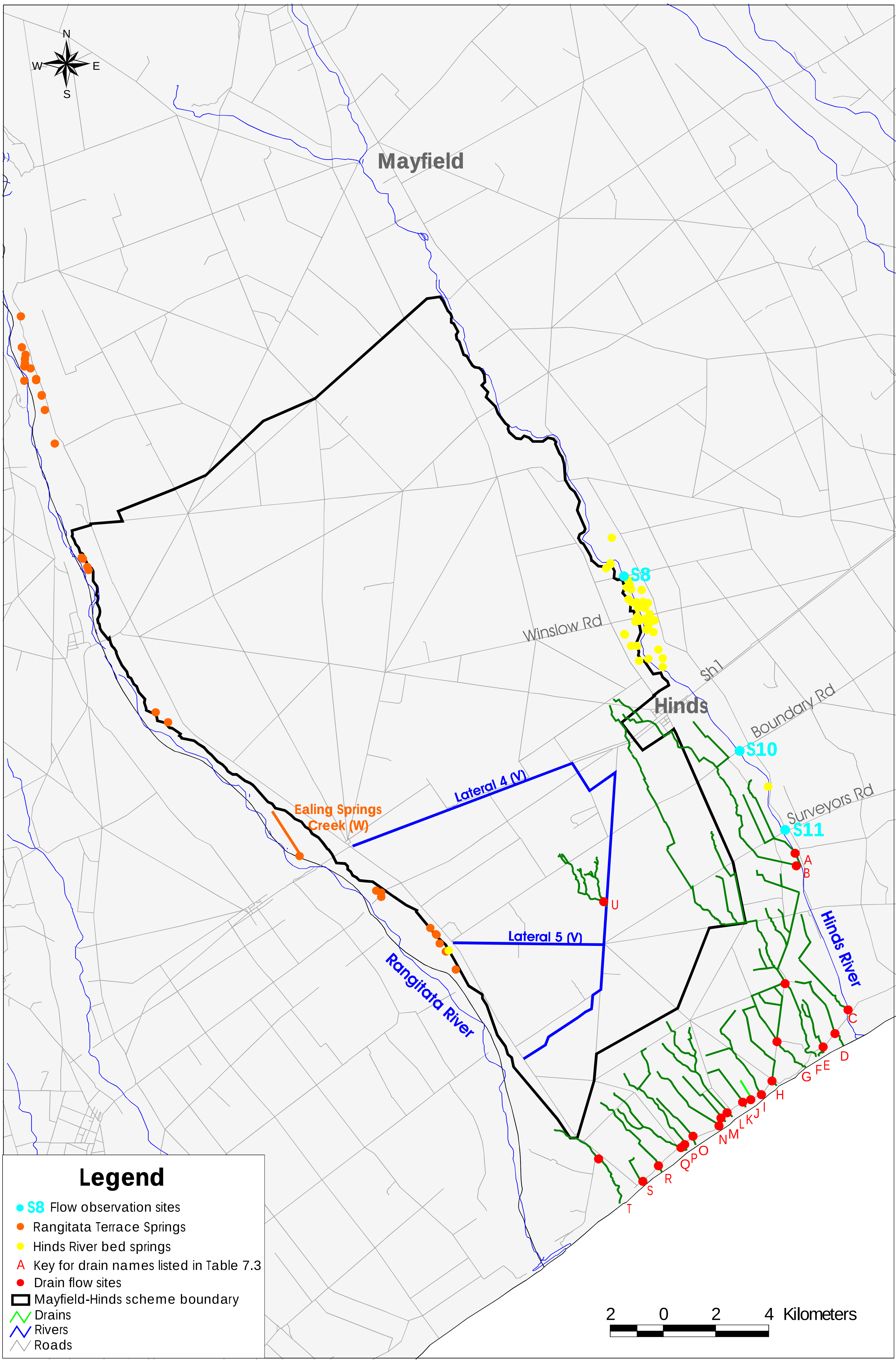

Figure 7.2 - Location of drains and springs discharging groundwater from the Hinds Rangitata Plain.

Key

	Gauged two weekly or less (from Sep 2005 - Sep 2006)
	Gauged once or twice twice (in Dec 05 and Jan 06)
	Visual flow observations
	Landowner flow observation

Time Period

1	1/09/05 - 30/11/05
2	1/12/05 - 1/03/06
3	2/03/06 - 31/05/06
4	1/06/06 - 31/08/06

At Oakdake Drain, the flow is known to increase by approximately 20 % downstream from where the drain was gauged. As a consequence, 20% was added to the flow at each time period. The total flow in Ealing Springs Creek was assumed to increase by 40 % downstream from where the Creek was gauged in March 2006. This would be likely, based on historical flow observations (Fish and Game, 2001).

Rangitata River Terrace Springs

There are a total of 40 springs along the Rangitata Terrace which discharge water into the Rangitata River via un-named creeks and gullies. No data is available on the flow from these springs, apart from landowner observations cited in Davey (2003). Landowners suggest that the average flow from each spring is 4 l/s. The flow from 38 springs (out of 40 springs) at the first time period was assumed to be 4 l/s each. The change flow over each time period was based on the changes in flow of Oakdale Drain, which is fed by Rangitata terrace springs near the coast. This was the closest reference point to extrapolate flow. Two of the springs were known to be dry prior too, but started flowing in time periods 3 and 4. The flow from these springs was provided (by way of a visual estimate) from the nearby landowner.

Hinds River

Over the course of this study, Hinds River site S11 (Figure 4.1 in the back pocket) had a relatively consistent flow of approximately 50 - 100 l/s from springs discharging groundwater within the bed of the river (Appendix 6.12). Between February and April 2006, water flowing from S8, sourced from springs within the bed of the river, joined with the flow of water halfway way between S10 and S11. Thus the flow at S11 provided an estimate of the groundwater discharge upstream from S11 to S8. The total discharge was based on the average monthly flow at S11, visually estimated from photos taken every two weeks (Appendix 6.12). Between May and August 2006 the flow at S11 was increased from an inflow of water further upstream. It was assumed however that the same quantity of groundwater discharged from this site over this later time period as well.

7.4 Discussion

A regional water balance of the Hinds Rangitata Plain was carried out for a one period, between September 2005 and August 2006. The one year period was broken into quarters, and the relative contribution from each component was totaled for each of the four time periods. A schematic block diagram showing the total volume of water from each recharge and discharge component over the one year time period is shown in Figure 7.3

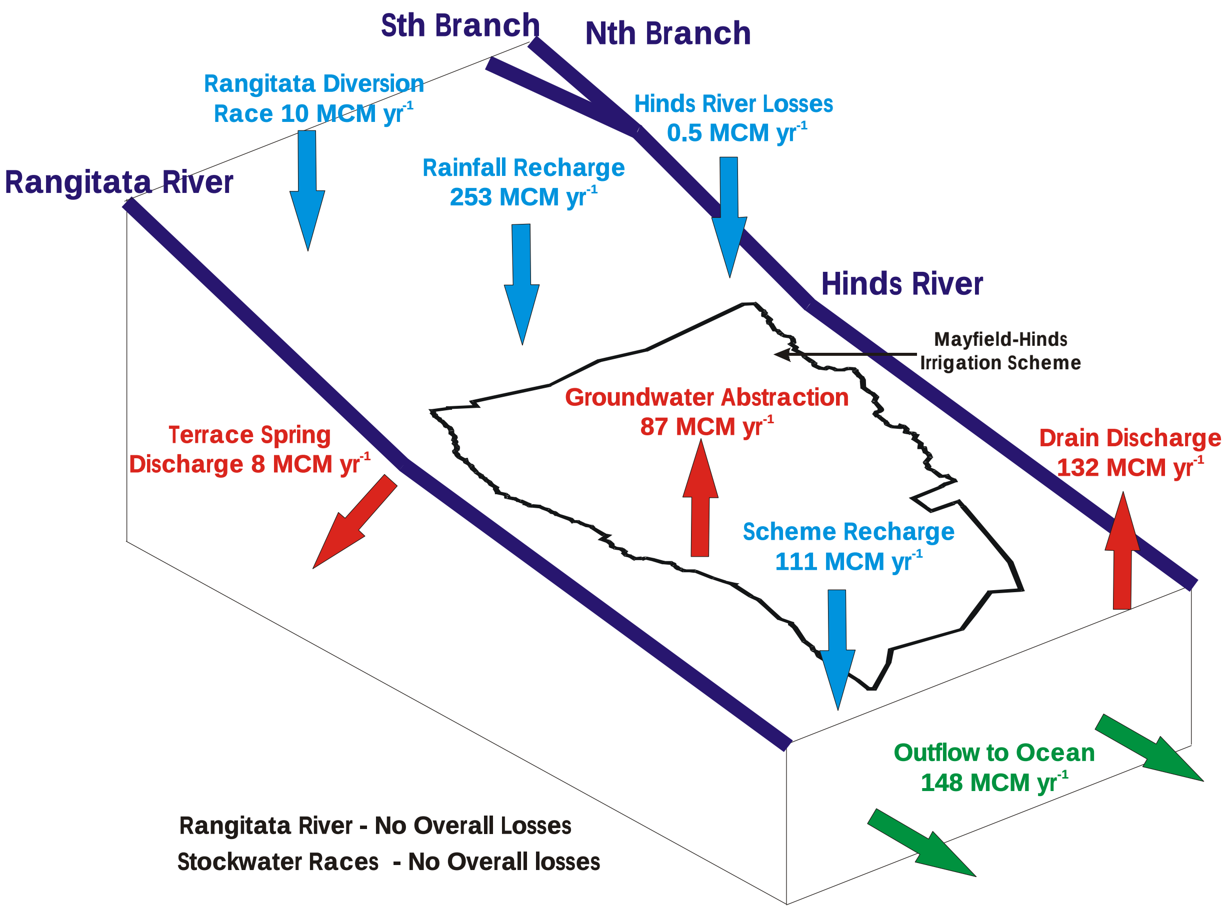

Figure 7.3 – Regional water balance showing the recharge and discharge components of the Hinds Rangitata Plain from September 05 – August 06.

From the water balance, rainfall recharge is shown to be dominant, and accounted for 67 % of the total recharge. Because rainfall during the 2005/06 irrigation season was one of the lowest on record, and rainfall during winter 2006 was one of the wettest on record, recharge during the first two and last two time periods may reflect the minimum and maximum recharge values for rainfall recharge.

Recharge from the Mayfield-Hinds Scheme accounted for 30 % of the total recharge, with a relatively small contribution each from the Rangitata Diversion Race and Hinds River. Despite the Mayfield-Hinds Scheme accounting for less recharge than rainfall, scheme recharge within the boundaries of the scheme is likely to be greater than the rainfall recharge occurring within the scheme boundary. Rainfall recharge over the entire Hinds Rangitata Plain is generally greater because it occurs over a larger area.

In terms of discharge, the discharge from drain flows (including Hinds River discharge) and Rangitata River terrace spring flow, accounted for 62 % of the total discharge, with the remaining discharge occurring from groundwater abstraction. As previously mentioned, there are no overall losses to groundwater from either the Rangitata River or from stockwater races. Thus, neither was accounted for in the water balance.

The volume of water from each recharge and discharge component during each quarter is presented in Table 7.4. Over the 2005/06 irrigation season the Mayfield-Hinds Scheme accounted for approximately 64 % of the total recharge. Based on the low summer rainfall and high scheme water usage during this period, it is unlikely that the Mayfield-Hinds Scheme would usually account for this much of the total recharge. Despite a significant recharge contribution from the scheme, total drain discharges remained relatively unchanged. The flow in drains located in Zone 1 (refer to Figure 4.1 in the back pocket) rose significantly throughout the irrigation season. However, the majority of the drainage network occurs in Zone 3 where groundwater levels were shown to be dominantly affected by rainfall. As consequence, drain flows showed the greatest response to heavy rainfall during winter 2006.

Table 7.4. – Seasonal variation in groundwater recharge and discharge from the Hinds Rangitata Plain groundwater system, as taken from September 05 – August 06.

Time Period	Recharge (m^3 x 10^6)				
	Rainfall	Hinds River	RDR[1]	MHIS[2]	**Total**
1/09/05 - 30/11/05	17	0.1	2.5	33	**53**
1/12/05 - 1/03/06	23	0.1	2.5	51	**77**
2/03/06 - 31/05/06	99	0.1	2.5	27	**129**
1/06/06 - 31/08/06	114	0.2	2.5	0	**117**
Total	**253**	**0.5**	**10**	**111**	**375**

Time Period	Discharge (m^3 X 10^6)				Outflow
	Drain Flows	Terrace Springs[3]	Gw Abstraction	**Total**	
1/09/05 - 30/11/05	18	1	33	**52**	**1**
1/12/05 - 1/03/06	17	1	33	**51**	**26**
2/03/06 - 31/05/06	36	2	21	**59**	**70**
1/06/06 - 31/08/06	61	4	0	**65**	**52**
Total	**132**	**8**	**87**	**227**	**148**

Key

1 Rangitata Diversion Race
2 Mayfield-Hinds Irrigation Scheme
3 Rangitata River Terrace Springs

The combined groundwater discharge for drain flow, and springs emanating from the northern bank terrace of the Rangitata River, accounted for a significant proportion of the total discharge. During the irrigation season, these discharges accounted for approximately 40 % of the total discharge, and 100 % of the total discharge during winter 2006.

Recharge from the Hinds River is shown to be relatively minor. This was due to the river remaining largely dry downstream from Mayfield Bridge to Boundary Road during the irrigation season. Significant flow occurred during winter 2006, however no accurate flow recorder, and no flow loss gaugings mean that it was difficult to determine the actual losses to groundwater between Mayfield Bridge and Boundary Rd. Downstream of Boundary Road, the Hinds River shows no discernable losses or gains, except when receiving foothills feed river flow. Significant flow losses from the Hinds River South branch may occur upstream of Mayfield-Bridge, however no gaugings were carried out on this section of the river.

Losses from the Rangitata Diversion Race (RDR) are shown to be moderately significant. However, much of the water lost between Klondyke and Cracroft where the race runs parallel to the Rangitata River, is likely to return back into the Rangitata River. Evidence for this is shown by the Mayfield-Hinds Scheme Main Race, which causes groundwater levels to rise close to the Rangitata River. In contrast, water lost from the RDR where it crosses the Plain between the Hinds and Rangitata Rivers, is likely to flow coastward, and thus remain within the groundwater system for a longer period of time.

Groundwater outflow to the ocean is shown to be highly variable depending on the ratio of recharge to discharge. It is likely that during certain periods of time, groundwater discharge may be greater than groundwater recharge. In addition, the effects of groundwater abstraction may be different in different aquifers, with discharge greater than recharge in one aquifer and the opposite in another. However, this water balance only looked at the groundwater system as a whole, thus the effects on separate aquifers is not yet known at this stage.

7.5 Summary

A regional water balance of the Hinds Rangitata Plain was carried out for a one period, between September 2005 and August 2006. During this period, total recharge was 375 m^3 x 10^6, total discharge was 227 m^3 x 10^6, and the outflow was 148 m^3 x 10^6. Data collected during the course of this study showed that rainfall recharge was dominant, accounting for 67 % of the total recharge. The Mayfield-Hinds Scheme accounted for 30 % of the total recharge, with a relatively small contribution each from the Rangitata Diversion Race and Hinds River. In terms of discharge, the combined discharge from the drains and Rangitata River terrace springs, accounted for 62 % of the total discharge, with the remaining discharge from coming from groundwater abstraction. There are no overall losses to groundwater from either the Rangitata River or from stockwater races.

As a consequence of low summer rainfall, the Mayfield-Hinds Scheme accounted for approximately 64 % of the total recharge from the Hinds Rangitata Plain, over the 2005/06 irrigation season. Despite a significant recharge contribution from the scheme, drain discharges were shown to be dominantly effected by rainfall. Groundwater outflow to the ocean is shown to be highly variable depending on the ratio of recharge to discharge.

Chapter Eight

Hydrochemical Facies

8.1 Introduction

Three water sampling programmes were undertaken during the course of this study. Samples were taken from a number of surface bodies and wells and analysed for a variety of chemicals. The main objectives of the sampling programme were:

- To characterise the different types of groundwater and surface water in the field area and identify trends in water chemistry both spatially and with depth.
- To identify recharge sources and groundwater flow paths based on Stiff plots, piper diagrams and a regional pattern of oxygen isotope 18 ($d^{18}O$).

8.2 Previous Sampling and Work

Regular annual groundwater quality monitoring in the Hinds Rangitata Plain has been conducted by Environment Canterbury since about 1988. This involved annual sampling of 10 first aquifer wells, most of which are restricted to the central part of the plain (Appendix 8.1). To obtain more information on the seasonal variation of groundwater chemistry seven wells have been sampled quarterly from June 2005 (refer to Abraham, Hanson and Smith, 2006).

Past reviews of the groundwater chemistry have been carried out by Swete (1987) who briefly described the spatial trends, Pattle Delamore Partners (2002) who looked at the impacts of irrigation and Environment Canterbury in their annual groundwater quality monitoring reports (from 2001 – 2005). The most detailed work thus far has been carried out by Abraham, Hanson and Smith (2006) who describe the regional chemistry and $d^{18}O$ of the field area both spatially and with depth. In addition, $d^{18}O$ and groundwater age studies of seven wells within the study area have been carried out by Stewart, Trompetter and van der Raaij (2002) and Stewart (2006).

8.3 Chemical Sampling Programmes

8.3.1 Seasonal changes in chemistry

Between August 2005 and September 2006, chemistry and $d^{18}O$ samples were collected from 7 wells (6 in aquifer one, 1 in aquifer two) in order to identify sources of recharge and the effects of recharge on water chemistry (Appendix 8.1). Between February and September 2006 anion (bicarbonate, chloride, sulphate and nitrate) samples were taken at each of the seven two weekly drain gauging sites (Appendix 8.2). All sampling was carried out by the author until May 2006 after which time samples were collected by Environment Canterbury. The results and discussion of the seasonal changes in groundwater and drain water chemistry is not presented in this thesis but will be written up on completion of this study.

8.3.2 Regional chemistry

Between November and December 2005, chemistry, *E.Coli* (from seven drain sites) and $d^{18}O$ samples were collected from 68 wells, 4 tile drains, 1 spring and 15 surface water sites in order to describe the regional water chemistry and identify sources of recharge (Figure 8.1). Results are presented in Appendix 8.3 a - b. Sampling was carried out by the author and staff from Environment Canterbury. For an additional discussion of the regional groundwater chemistry, refer to Abraham, Hanson and Smith (2006).

8.4 Sampling Methodology

Chemistry samples were analysed by Environment Canterbury's laboratory in Christchurch and $d^{18}O$ samples were analysed at the Institute of Geological and Nuclear Sciences (GNS), Wellington, New Zealand. In addition to the laboratory analyses, conductivity, pH, temperature and some dissolved oxygen measurements were made in the field. All samples were collected following the procedures outlined in the Surface Water Quality, Groundwater Quality, Biological and Habitat Assessment Field and Office Procedures Manual (Environment Canterbury, 1999).

In order to ensure that the sampled well water was truly representative of the aquifer, wells were purged by pumping a minimum of three times the volume of water in the casing. Samples were

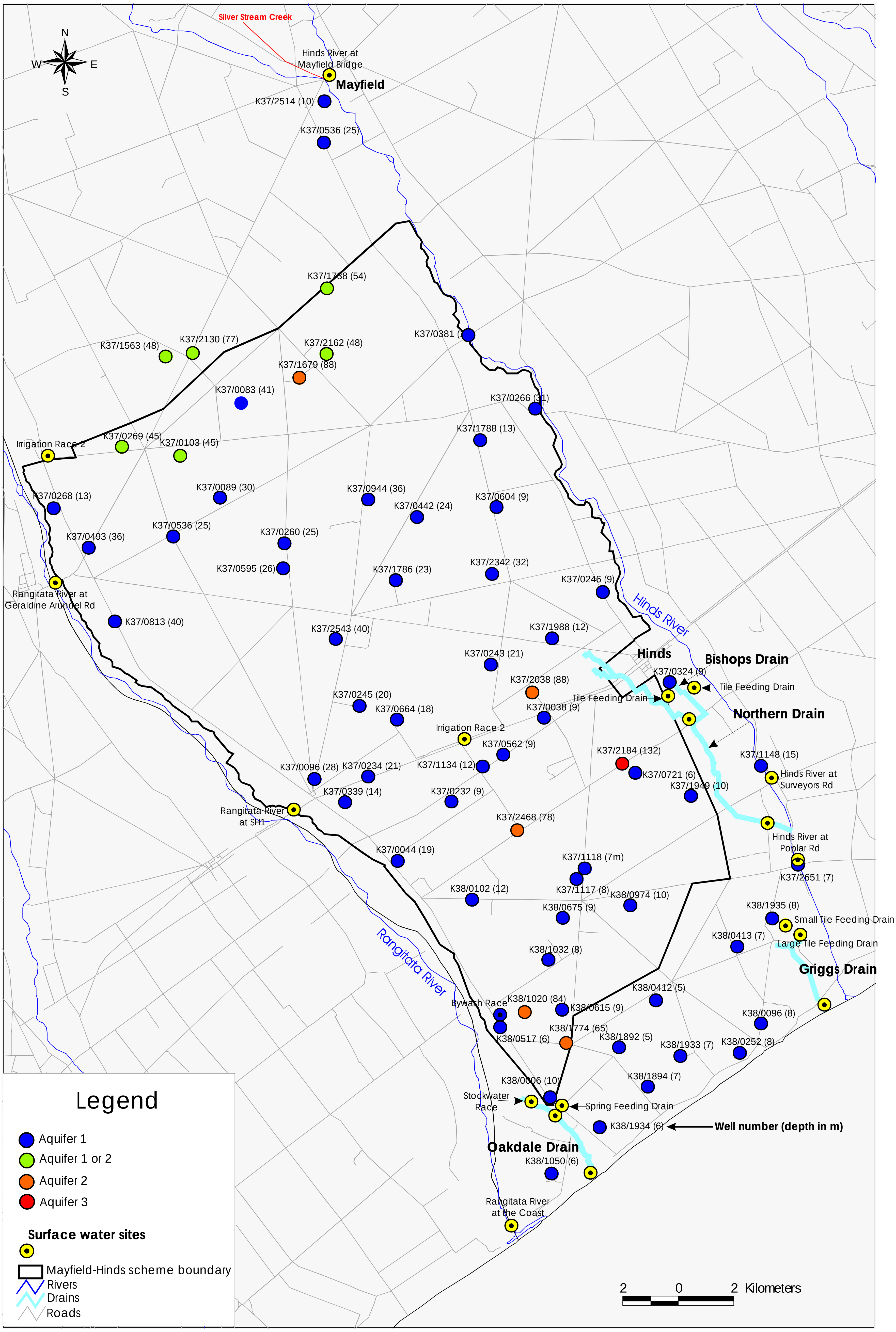

Figure 8.1 - Distribution of well, river, irrigation race and drain water chemistry sites sampled between November and December 2005.

collected once the conductivity, pH and temperature had stabilized. The lids of all d^{18}O sample bottles were tapped to prevent contamination from air outside the bottles.

8.5 Groundwater Chemistry and Recharge Sources

In general the chemical compositions of shallow groundwater derived from river water and rainfall recharge is different. Rainfall reacts with minerals and nutrients on passage through the soil, causing the enrichment of ions including magnesium, calcium and chloride. The degree of enrichment reflects both the soil type and land use. This enrichment is evident in the soils at the Hororata Lysimeter (Table 8.1). Chloride is highly enriched, changing from an average of 3.72 mg/l to an average of 16.4 mg/l on passage through the soil. In contrast to chloride, nitrate concentrations are increased to a lesser degree, and may be effected by site specific influences. In addition, there is little exchange of chloride within Canterbury plains aquifers meaning chloride concentrations are useful in distinguishing recharge sources.

Table 8.1 - d^{18}O, chloride and nitrate-nitrogen data for direct rainfall and rainfall recharge at the Hororata Lysimeter site (sourced from Stewart, 2005). Samples were taken once a month.

Year	**Rainfall**					**Soil Drainage**				**Sample Period**
	Depth	^{18}O	Cl	NO_3-N		Depth	^{18}O	Cl	NO_3-N	
	mm	$^0/_{00}$	mg/l	mg/l		mm	$^0/_{00}$	mg/l	mg/l	months
1999	496	-8.54				216	-9.03			6
2000	883	-8.84	2.88	<0.2		408	-9.69	8.06	0.05	12
2001	728	-7.02	2.4	<0.3		270	-6.92	20.61	0.68	12
2002	533	-8.58	3.3	<0.3		47	-8.28	4.74	<0.3	12
2003	741	-7.84	2.27	<0.3		230	-7.25	28.04	2.11	12
2004	577	-8.67	8.89	0		108	-8.05	17.68	1.76	12
Means	**692**	**-8.17**	**3.72**	<0.3		**213**	**-8.23**	**16.4**	**0.83**	

In contrast to rainfall recharged groundwater, river recharged groundwater has lower ionic concentrations including low nitrate (< 3 mg/L) and low chloride (< 3 mg/L) concentrations. This is caused by two factors. First, the lower ionic concentrations result from low ionic concentrations of the river water including low nitrate (<0.1 mg/L) and low chloride (< 1 mg/L) concentrations. Second, river recharge water bypasses the soil profile resulting in no mineral enrichment.

The chemical composition can also be influenced by other factors such as aquifer material, residence times and contamination. The general similarity in composition of the aquifer material over the field area suggests that geology will not significantly affect the groundwater chemistry.

8.6 Methodology for Describing Facies

Water samples were taken at different points along the Hinds River, Rangitata River and Irrigation Laterals so that groundwater samples could be compared to potential surface water recharge sources. Samples were also taken from four drains (Bishops, Northern, Griggs and Oakdale) in order to compare drain chemistry with potential groundwater recharge sources. Chemistry and $d^{18}O$ data are used to identify recharge sources and groundwater flow paths based on Stiff plots, piper diagrams and the regional pattern of $d^{18}O$.

8.6.1 Stiff plots

The groundwater and surface water chemistry was graphed into Stiff plots in order to identify groundwater recharge sources. The Stiff plot utilizes four parallel horizontal axes which extend on each side from a vertical zero axis. Cations are plotted as pairs on the left horizontal axis and anions on the right horizontal axis as pairs in units of millequivalents per litre. Typical anion – cation pairs are: Ca – HCO_3, Mg – SO_4, Na + K – Cl and Fe – CO_3. For this study the Fe – CO_3 axis was replaced by Fe – NO_3 because of the potential for NO_3 to distinguish between rainfall and river recharge. When the points of the plot are connected a distinctive polygon pattern is produced.

Polygons were sorted into 8 groups of similar shapes, each group representing a distinct chemical signature, indicative of a particular combination of recharge sources. Each distinct group is represented by a particular color (Appendix 8.4 a - b). The spatial distribution of all Stiff plots is shown in Figure 8.2. The $d^{18}O$ values correlate well to the recharge sources interpreted from each Stiff plot pattern and are provided in each description.

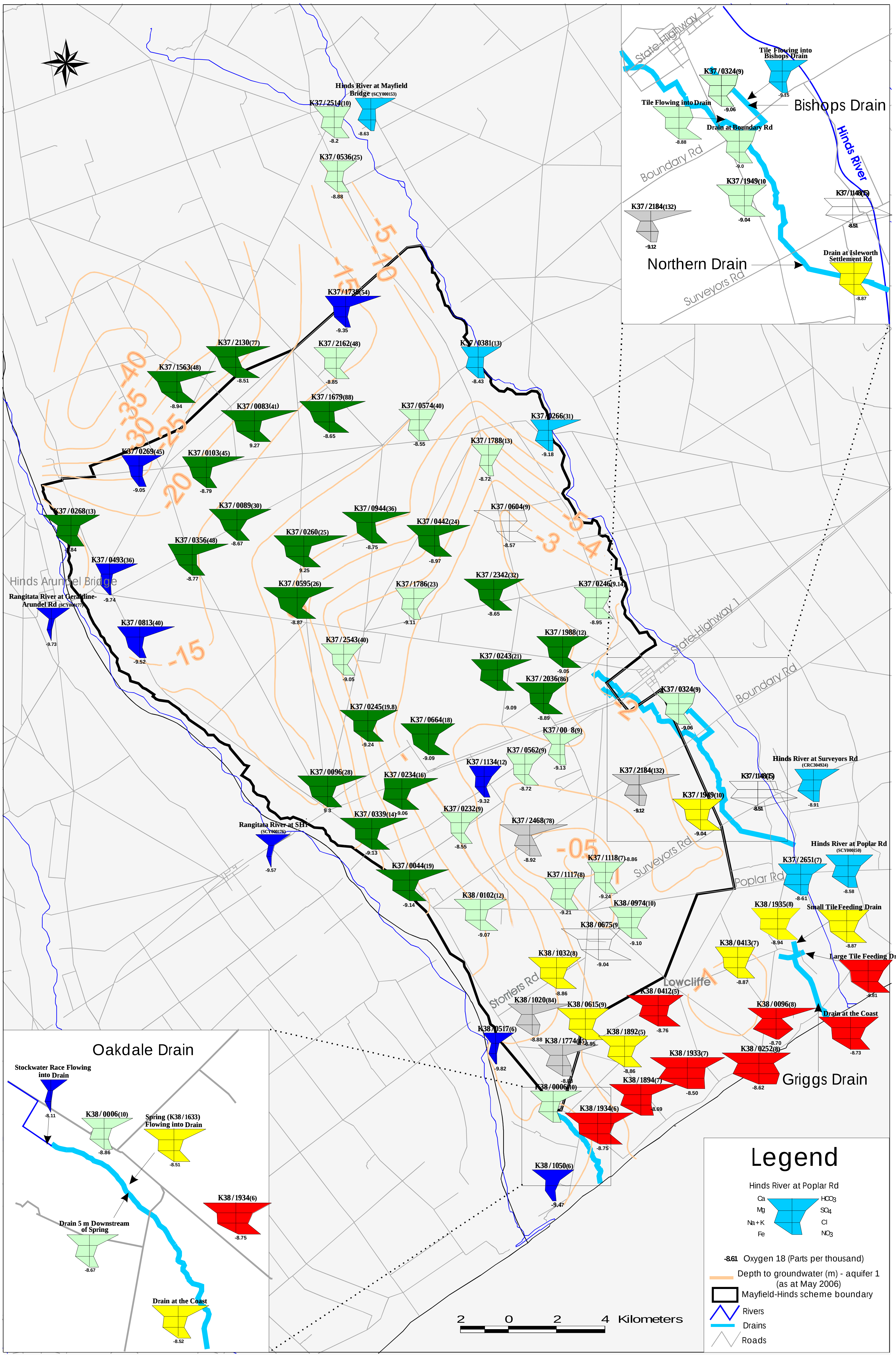

Figure 8.2 - Distribution of stiff plot patterns from sampled wells, rivers, irrigation races and drains.

8.6.2 Piper diagrams

Piper diagrams were used to identify different water types (hydrochemical facies) and potential sources of recharge. The major cations (Ca, Mg, Na + K) and anions (HCO_3 + CO_3, Cl, SO_4) were plotted as percentages of the equivalent weights (meq/L) on triangles to form a point. Each cation and anion point was then projected onto a diamond shape field until the points intersect. This point of intersection determines the hydrochemical facies. Samples collected as part of this study were projected onto a four separate piper diagrams (Figures 8.3 – 8.6).

8.7 Water Types

Stiff plot patterns show three types of groundwater: Calcium Bicarbonate, Calcium Nitrate and a Non Dominant Type (Appendix 8.4 a - b). Piper diagram shows two types of groundwater: Calcium Bicarbonate and a Non Dominant Cation Bicarbonate Type (exception is well K3/1148) (Figure 8.3). The Calcium Bicarbonate Type (28 wells and 3 drain sites) is restricted to wells between 25 and 60 m deep. Spatially these wells occur adjacent to the Rangitata River and inland of Sate-Highway 1 (but not within 4 km of the Hinds River). The Non Dominant Type and Non Dominant Cation Bicarbonate Type (36 wells and 6 drain sites) are restricted to wells within 4 km of the Hinds River and east of State-Highway 1. Two wells, one near Lismore (K37/0604) and one 7 km inland from the coast (K38/0675) were a Calcium Nitrate Type.

Stiff plot and Piper diagrams shows show two types of river water: The Calcium Bicarbonate Type found in all Rangitata River derived water has a high percentage of calcium and bicarbonate. The Non Dominant Type found in all Hinds River sampled sites has a smaller percentage of calcium and bicarbonate. Downstream from Mayfield-Bridge, the Hinds River gains a greater percentage of sulphate and smaller percentage of bicarbonate.

8.8 River Sourced Recharge

8.8.1 Overview

When the chemistry and $d^{18}O$ value of the groundwater is similar to the river, it is likely that the groundwater is at least partly derived from the river. Figure 8.4 plots the points for selected dark

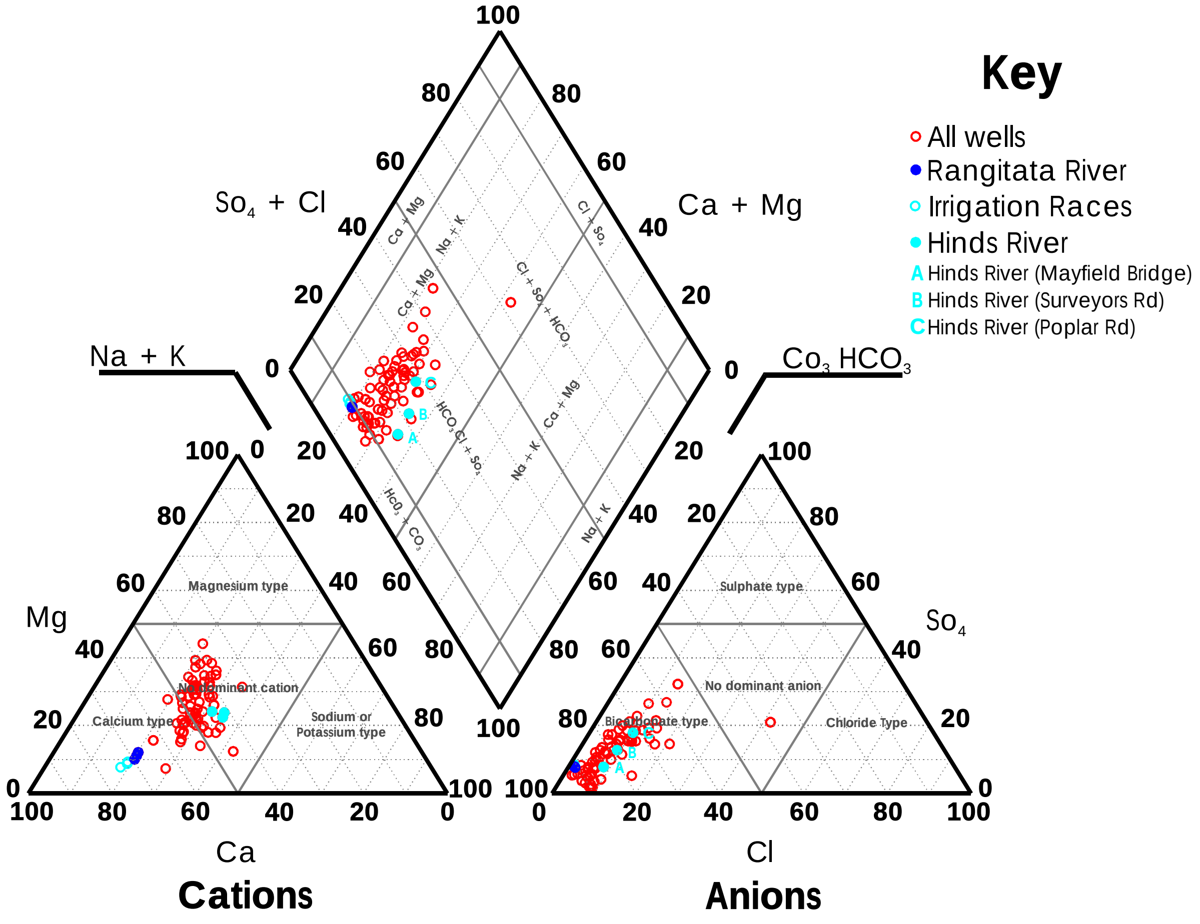

Figure 8.3 - Piper diagram for all groundwater Stiff plot patterns, and river sourced water.

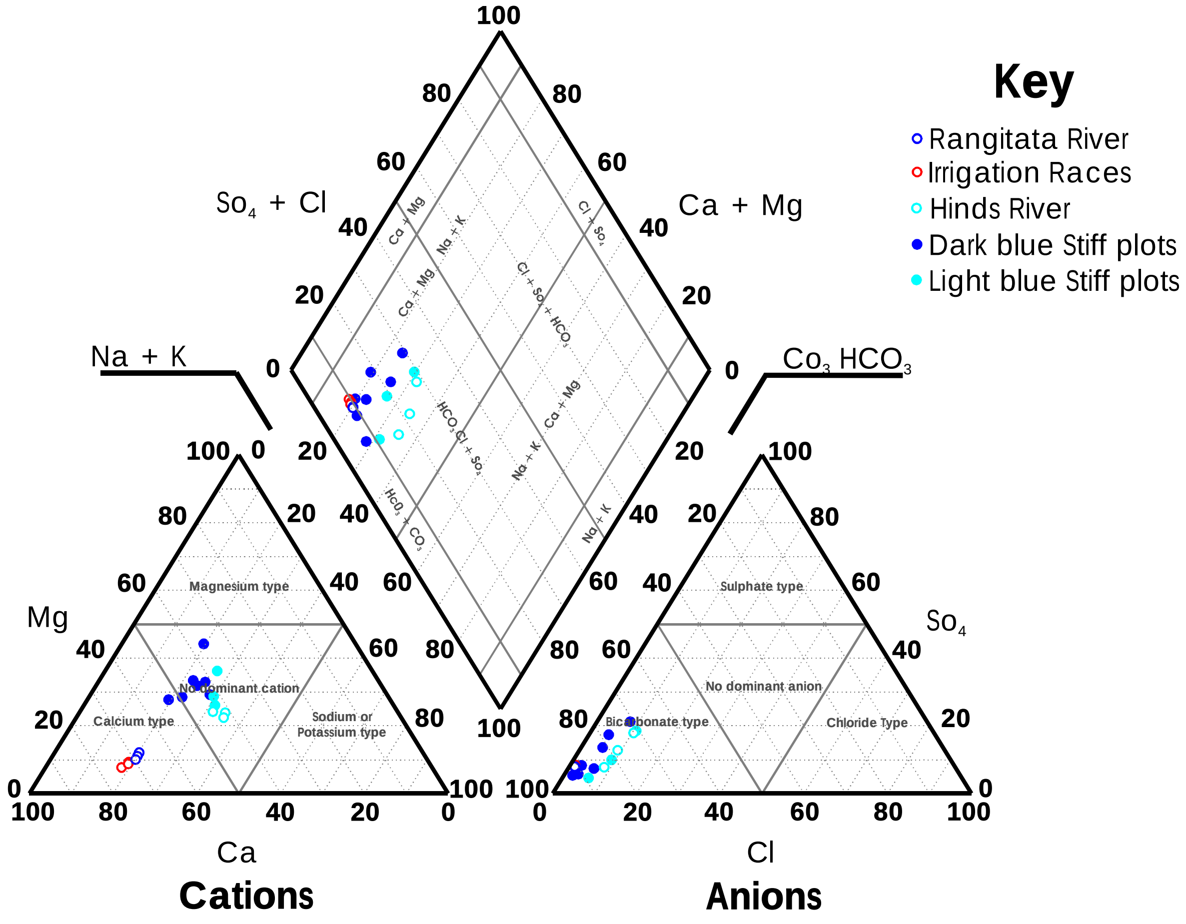

Figure 8.4 - Piper diagram for selected groundwater Stiff plot patterns, the Hinds River and Rangitata River.

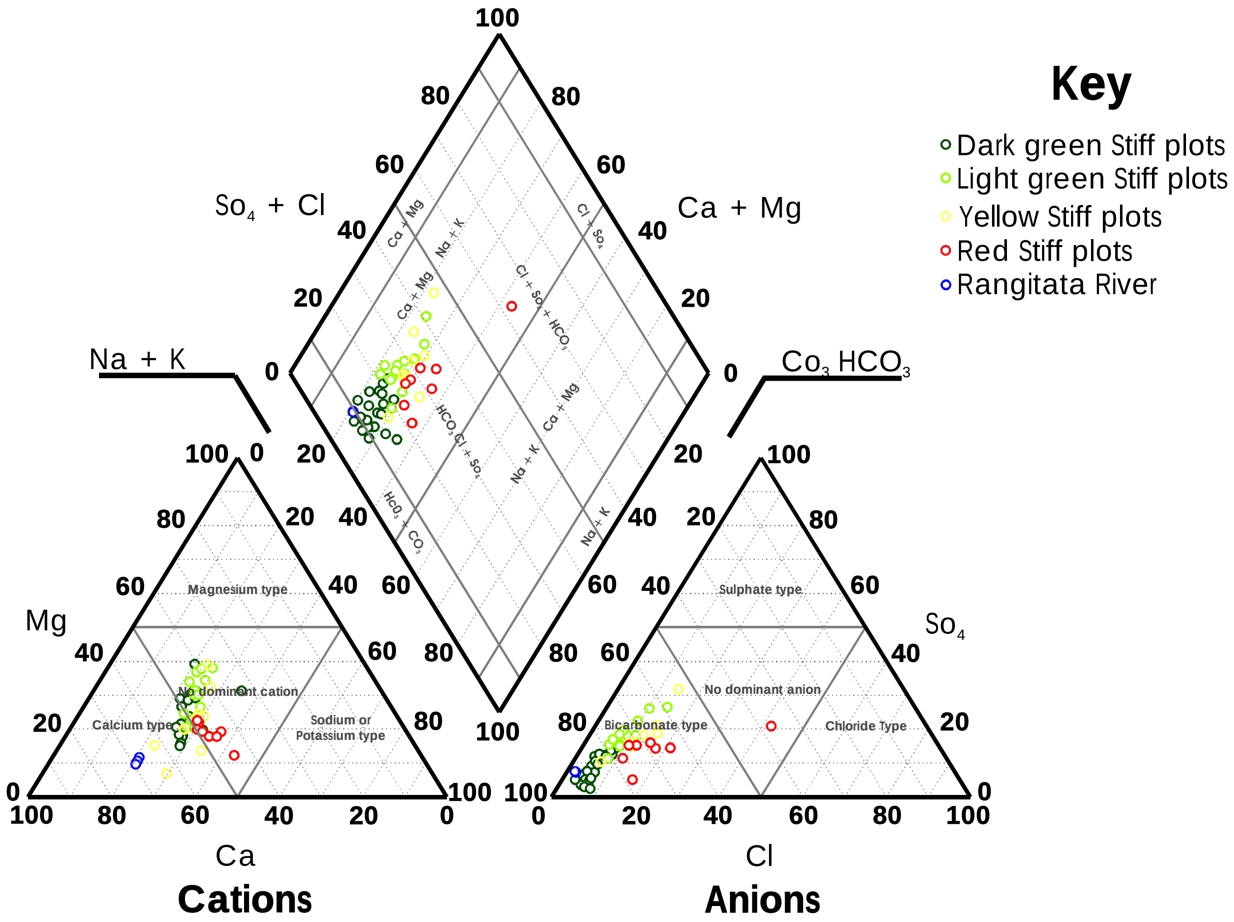

Figure 8.5 -Piper diagram for selected groundwater Stiff plots and the Rangitata River.

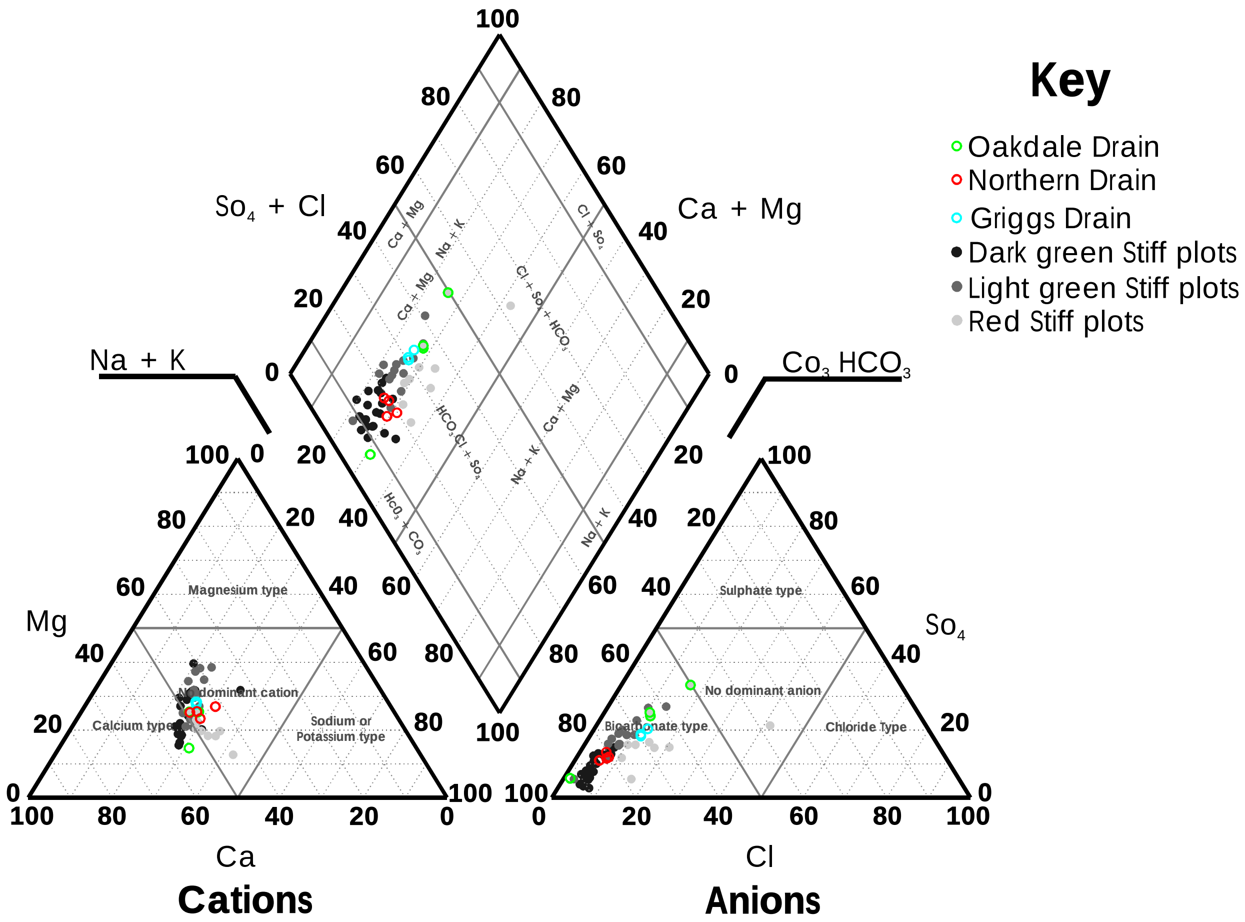

Figure 8.6 - Piper diagram for selected groundwater Stiff plots and all drain sites.

blue (Rangitata River recharged) and light blue (Hinds River recharged) Stiff plot patterns in conjunction with Rangitata River and Hinds River water.

With increasing distance from the Rangitata River, groundwater in aquifer one has a smaller percentage of bicarbonate and greater percentage of chloride. The percentage of sodium + potassium increases most rapidly with increasing distance from Rangitata River, in contrast, the percentage of bicarbonate decreases by a relatively smaller amount. Increased percentage of sodium + potassium and chloride with increasing distance from the Rangitata River, likely reflects a greater contribution from nutrient enriched rainfall recharged water.

In contrast to the Rangitata River, the chemical composition of the Hinds River was more similar to the groundwater adjacent to the river. The only notable difference was that the Hinds River had a slightly higher percentage of sodium + potassium compared to the adjacent groundwater.

8.8.2 Rangitata River recharge (dark blue Stiff plots)

The groundwater chemistry in wells K38/0517 and K38/1050 (both in aquifer one) suggest surface water losses from the Rangitata River downstream of Storriers Rd (Figure 8.2). Well K38/0517 is closer to the Rangitata River which may account for the lower ionic concentrations and more negative $d^{18}O$ value compared with well K38/1050. Flow gaugings and historic piezometric contour maps (South Canterbury Catchment Board, 1975) suggest that the river gains in flow downstream of Storriers Rd (Chapter 6.4). However, landowner reports cited in Oliver (1946 c), piezometric contours, water level fluctuations, relict channels and fan topography, all suggest some river losses. Based on water level fluctuations from wells K38/0517 and K38/1310, it would seem that aquifer one receives a relatively constant seepage of Rangitata River water downstream of Storriers Rd.

Two wells nearer the middle of the Hinds Rangitata Plain (K37/0269 and K37/1738) occur near main races (both within 100 m of Lateral 1) and have a dark blue Stiff plot pattern suggesting significant race losses. Wells K37/0493 and K37/0813 (both in aquifer one) occur close to the Rangitata River (within 1.5 km) and Main Race (within 200 m) and both have dark blue Stiff plots. This suggests one or a combination of Rangitata River and Irrigation race recharge to each well, however the relative recharge from each source is unknown.

One shallow first aquifer well (K37/1134) near the Old Main South Rd also had a dark blue Stiff plot pattern. This well is far away from the Rangitata River and not close to a main race (1.2 km from Lateral 4), but is located 15 m down-gradient of a border-dyke paddock. Thus it may be possible that the well receives direct border-dyke recharge with the sample being taken soon after the watering of up-gradient border-dyke paddocks.

8.8.3 Hinds River Recharge (light blue Stiff plots)

All Hinds River samples were predominantly groundwater sourced as the Hinds River south branch (at Mayfield-Bridge) where significant rainfall sourced water comes from, was dry at the time of sampling. The sample at Mayfield Bridge was derived from Silver Stream Creek, likely to be spring sourced (shown in Figure 8.1) and possibly some water from the north branch. Water from Surveyors Rd and Poplar Rd was derived from a combination of springs within the river bed and groundwater feed drains flowing into the river. Had the Hinds River been flowing for its entire length from foothills (rainfall) sourced river water the chemistry and $d^{18}O$ signatures of the Hinds River and adjacent wells may have been different (refer to section 8.10, Hinds and Rangitata Rivers).

The Hinds River and adjacent groundwater water shows a steady increase in the overall ionic concentrations, a decrease in bicarbonate (as a percent) and increase in sulphate (as a percent), nitrate and chloride with increasing distance downstream of Mayfield Bridge (Figure 8.3). This pattern clearly shows the increasing dominance of groundwater as a source of river flow and groundwater recharge with increasing distance downstream from Mayfield Bridge. Generally groundwater has higher nitrate and chloride concentrations than rainfall feed rivers.

Wells K37/0381 (32 km inland) and K37/0266 (25 km inland) show a relatively thin (low ionic concentration) light blue Stiff plot pattern despite foothills sourced river flow never extending downstream to either well for at least 12 months prior to sampling. This could occur if Hinds River water which is lost to groundwater further upstream, moves downstream within and adjacent to the bed of the Hinds River. This could occur if the Hinds River recharge water is preferentially contained within the narrow strip of (Hinds River deposited) postglacial gravels either side of the modern day river channel. This mode of groundwater occurrence was noted by Wilson (1973). Another explanation could be that Hinds River water within adjacent groundwater was sourced at a time when the river was flowing further downstream. This water may continues flowing downstream (but underground) within and adjacent to the bed of the river well after the river (in this section) dries up.

The higher ionic concentrations of the Hinds River water at Surveyors Rd was caused by the flow being totally sourced from groundwater feed springs within the bed of the river. In addition, no foothills rainfall flow had joined with this section of the river for at least 12 months prior to sampling. The increased ionic concentration of the Hinds River water between Surveyors Rd and Poplar Rd was likely caused by inflow from the Northern Drain which accounted for at least 50 percent at the time of sampling. The average concentrations of nitrate and chloride from this drain were higher than the Hinds River water sampled at Surveyors Rd. The higher concentration in the river is reflected in the higher concentrations of well K37/2651 (aquifer one), adjacent to the Hinds River.

The light blue Stiff plot pattern was also recorded from a tile drain flowing into Bishops Drain. Bishops Drain runs parallel to the Hinds River (approximately 600 m away) and the tile drain (half way between State-Highway 1 and Boundary Rd) extends from Bishops Drain towards the river. Significant flow losses to groundwater from this section of the river were shown from gaugings (Chapter 6.5), piezometric contours (Chapter 4.9.3) and flow losses of bywash from Lateral 3. In addition significant flows of bywash occurred approximately one month prior to sampling. Thus it is likely that surface water lost from this section of the river recharges the water table to at least 600 m away from the river.

8.9 Rainfall and Irrigation Sourced Recharge

8.9.1 Overview

Stiff plot patterns show the change in groundwater chemistry down Plain, from the inland edge of the scheme to the coast (Figure 8.5). The general order moving down plain is dark green (15 – 30 km inland), light green (5 – 15 km inland and adjacent to the Hinds River), yellow (3 – 6 km inland) and red (0 – 3km inland). Within the Mayfield-Hinds Scheme there is a progressive reduction in the percentage of bicarbonate and progressive increase in the percentage of sulphate down Plain. In contrast, the percentage of chloride remains relatively similar, with no spatial trend in cations. Between the Mayfield-Hinds Scheme and the coast, total ionic concentrations are greatest and the percentage of chloride increases. This is caused by coastal precipitation containing higher ionic concentrations and the reduction (or absence) of scheme recharge meaning that there is little or no dilution (from Rangitata River derived irrigation water) of the nutrient enriched rainfall recharge water. In general the dark green and light green Stiff plots represent dominantly scheme recharged groundwater, the red represent dominantly rainfall recharged groundwater and the yellow Stiff plots are intermediate between the two.

Within the Mayfield-Hinds Scheme, coastward of State-Highway 1, all second and third aquifer wells had a distinctly different chemistry (represented by the grey Stiff plots). The water from these aquifers is high in calcium and bicarbonate and low in nitrate.

Three wells, each with clear Stiff plot fills, had a chemistry which did no fit with any of the Stiff plot groups. Two of the wells had Calcium Nitrate Type water, a type not found in any other wells. In the other well (K37/1148), the total ionic concentrations were significantly higher in comparison to other wells.

Figure 8.6 plots the points for selected first aquifer Stiff plot patterns (dark green, light green and red patterns) and the three drains (Northern, Griggs and Oakdale). The dark and medium grey plots represent the dark and light green Stiff plot patterns which are dominantly Mayfield-Hinds Scheme recharged groundwater. The light grey plots represent the red Stiff plot patterns which are dominantly rainfall recharged groundwater. Each drain site was then plotted onto the piper in order to predict whether the drain was dominantly recharged by the Mayfield-Hinds Scheme or rainfall. The piper shows that water in the Northern Drain is dominantly Mayfield-Hinds recharged, the water in Oakdale Drain is partly scheme and rainfall recharged and that Griggs Drain is mainly rainfall recharged (though the chemistry is close to some scheme recharged wells). This agrees with drain flow fluctuations observed during the course of this study (Chapter 6.3).

8.9.2 Dark green Stiff plots

Wells with this pattern occur in both aquifers one and two and are confined to an area where the depth to groundwater is relatively deep (aquifer one water level contours are shown in Figure 8.2). As discussed in Chapter 4.9.2 the depth to groundwater (in aquifers one and two) increases inland and towards the Rangitata River, a feature which is partly related to scheme recharge. This deeper water level area (as contoured for May 2006) roughly extends inland from State-

Highway 1 with the exception of a 4 km strip adjacent to the Hinds River. In this deeper water level area, groundwater levels in the first and second aquifers rose between 3 and 12 m in response to scheme recharge and between 1 and 5 m in response to heavy winter (2006) rainfall. Thus recharge from the Mayfield-Hinds Scheme is likely to be dominant with a smaller but still significant recharge contribution from rainfall.

One reason why the dark green Stiff plots do not occur close to the Hinds River or east of State-Highway 1 (with the exception of a small area below Ealing) may be related to the deeper depth to groundwater. As previously discussed in Section 8.5, water reacts with minerals and nutrients on passage through the soil resulting in enrichment of a number of ions including calcium, magnesium and chloride. In addition, dissolution of silicate minerals from drainage through the aquifer matrix may contribute further sodium, potassium, calcium, magnesium and bicarbonate (Burden, 1982). Thus the thicker vadose zone (unsaturated zone) further inland is likely to provide a greater opportunity for drainage water to gain nutrients and minerals before entering the groundwater system. This could be why the dark green Stiff plots have higher ionic concentrations and higher concentrations of calcium and bicarbonate, compared with the light green Stiff plots which occur in a higher water table area.

Nitrate leaching from border-dyke irrigated pasture is far greater than from non-irrigated pasture (Burden, 1982). Though border-dyke irrigation may increase the total quantity of nitrate draining into the groundwater the overall quantity is not high as may be expected, with an average nitrate concentration of 6.4 mg/L and highest concentration of 9.0 mg/L (maximum guideline value is 11.3 mg/L). The lower than expected nitrates may result from a dilution effect attributed to the large quantity of low nitrate concentration irrigation water (shown by the 3 – 12 m water level rise) applied each summer (Burden, 1982). Thus concentrations are kept low because the nitrates are dispersed within a larger body of water. In addition, consistent summer drainage under border-dyke irrigation may also reduce the build up of nitrates in the soil thus causing seasonal variations in nitrate to be lower than those beneath spray irrigated or dry-land areas.

8.9.3 Light green Stiff plots

In contrast to the dark green Stiff plots, overall ionic concentrations are lower, in particular, calcium, bicarbonate and to a lesser extent nitrate concentrations all decrease (Figure 8.2). Wells with this pattern occur in aquifer one and are confined to the higher water table area within the Mayfield-Hinds Scheme (down-gradient of State-Highway 1 and up-gradient of State-Highway 1 close to the Hinds River) and adjacent to the Hinds River near Mayfield Township. Within in the scheme, water levels in the first aquifer rose between 1 and 5 m in response to scheme recharge and between 0.5 and 3 m in response to heavy winter (2006) rainfall. Thus recharge from the scheme is likely to be dominant, with a smaller but still significant recharge contribution from rainfall. Near Mayfield Township, the two wells with the light green Stiff plots were recharged by a combination of Hinds River water and rainfall. The lower overall ionic concentrations and lower nitrates (average 4.5 mg/L) in contrast to the dark green Stiff plot (average 6.4 mg/L) may be related to a higher water table and thinner vadose zone resulting in less nutrient and mineral enrichment of the drainage water. In addition, the lower than expected nitrate concentrations may also result from a dilution effect in wells located within the Mayfield-Hinds Scheme and from the Hinds River in wells located near Mayfield Township.

The light green Stiff plots were also recorded from a tile drain flowing into the Northern Drain (approximately half way between State-Highway 1 and Boundary Rd) and from the Northern Drain 50 m upstream of Boundary Rd. These light green Stiff plots suggest a recharge contribution from the Mayfield-Hinds Scheme. This is evident by the progressive increase in flow over the 2005/06 irrigation season (shown in Chapter 6.3.3).

8.9.4 Yellow Stiff plots

Wells (first aquifer only) with this pattern generally occur within a high water table area (1 – 4 m below ground level) near the coastward edge of the Mayfield-Hinds Scheme and near Lowcliffe (Figure 8.2). Groundwater levels within the coastward area of the scheme rose 1 - 3 m in response to Mayfield-Hinds Scheme recharge and 0.5 - 1.5 m in response to heavy winter (2006) rainfall indicating a contribution of both Mayfield-Hinds Scheme and rainfall recharge. In contrast the groundwater levels near Lowcliffe did not rise in response to Mayfield-Hinds Scheme recharge but did respond to local rainfall events suggesting a dominantly rainfall recharge influence. The higher ionic concentrations, higher chloride and higher nitrate concentrations suggest a smaller dominance of scheme recharge and increasing dominance of local rainfall. However, the average $d^{18}O$ value was -8.9 $^{0}/_{00}$, compared with -9.0 $^{0}/_{00}$ for both the dark and light green Stiff plot patterns, suggests that scheme water is the dominant sourced of recharge for the yellow Stiff plots. The highly negative $d^{18}O$ in yellow patterns nearer Lowcliffe suggests a gradual seepage of scheme water without any obvious rise in the water table (as water levels in this area did not rise over the 2005/06 irrigation season).

Yellow Stiff plots were also recorded from the Northern Drain (near the Hinds River), Oakdale Drain at the coast and a spring draining into Oakdale Drain. The yellow Stiff plot recorded from the Northern Drain likely resulted from an increased contribution from rainfall recharged groundwater which flows into the drain between Boundary Rd and Isleworth Settlement Rd. Groundwater level fluctuations show that this area is dominantly rainfall recharged. The two yellow Stiff plots recorded from Oakdale Drain reflect the dominance of rainfall recharge with a relatively minor recharge contribution from the scheme. This is evident by the flow in Oakdale Drain and the adjacent groundwater level fluctuations, both of which were more effected by rainfall (Chapter 6.3.6).

8.9.5 Light grey Stiff plots

Of the light grey Stiff plots, one well occurs in aquifer three (90 – 130 m depth) three occur in aquifer two (40 – 90 m depth) and one well occurs in aquifer one (0 – 40 m depth). All wells are located coastward of State-Highway 1 and within the Mayfield-Hinds Scheme. Within the scheme, groundwater levels in aquifers one and two rose in response to both scheme and rainfall recharge indicating a combination of scheme and rainfall recharge. Aquifer three likely showed a delayed scheme recharge effect and water levels rose with rainfall, thus both are sources of recharge.

The light grey Stiff plots are characterized by high concentrations of calcium and bicarbonate and low concentrations of nitrate. The lower nitrate concentrations in aquifers two and three likely occur from a reduction in nitrate concentrations with increasing depth. This may occur because of a reduction in the oxidation potential with depth and with increased distance from source of recharge (Hanson, 2002). Another possibility is that the nitrates from human activities have not yet penetrated down into to the deeper aquifers (Hanson, 2002). The high levels of bicarbonate may reflect a slightly different lithology in aquifers two and three.

8.9.6 Red Stiff plots

Wells with this Stiff plot occur in aquifer one (aquifer two not sampled in this area) and are confined to a high water table area within old Hinds Swamp, 3 – 4 km inland from the coast (Figure 8.2). In this area, water levels in aquifer one did not rise in response to scheme recharge but did rise in response to local rainfall events.

The higher ionic concentrations of the shallow groundwater occur as a result of three factors. First, precipitation chemistry in coastal regions closely reflects the relative abundance of ions in seawater (Burdern 1982). As a consequence, coastal precipitation has higher ionic concentrations especially sodium, magnesium, chloride and sulphate (Burden, 1982). Second, the absence of scheme recharge means that there is little or no dilution (from Rangitata River derived irrigation water) of the nutrient and mineral enriched rainfall recharge water. Third, high concentrations of salt deposited on the adjacent coast by sea spray, may be transported into the aquifer during recharge events.

The coast water table between the Hinds and Rangitata Rivers shows no signs of reduced groundwater. Reduced groundwater occurs from the decomposition of organic material such as peat. This consumes the available oxygen and the groundwater becomes strongly reduced, with ammonia nitrogen becoming dominant over nitrate nitrogen (Hanson, 2002). Blue oxidized gravels (indicative of a peaty wetland environment) were found 2 – 3 m below ground level near the coast (Chapter 3.2.2) and the entire coastal area occurs within the old Hinds Swamp. However, the high nitrate (average of 6.2 mg/L) and low ammonia nitrogen (0.0025 – 0.028 mg/L) concentrations in these coastal wells suggests no reduced groundwater.

The red Stiff plot patterns were also recorded from a Tile Drain flowing into Griggs Drain and from Griggs Drain just before flowing into the ocean. Seasonal fluctuations in flow show that this drain is dominantly rainfall recharged (Chapter 6.3.7). This agrees with the red stiff plot pattern and more positive $d^{18}O$ of the drain water, in comparison to groundwater further inland.

8.9.7 Transparent Stiff plots

Three wells with transparent Stiff plot fills had a polygon shape which did no fit any Stiff plot group (Figure 8.2). Two of the wells differed on the basis that they were a Calcium Nitrate Type water (a type not found in any other wells), causing a distinctly different shaped polygon. In well K37/1148 (adjacent to the Hinds River), the total ionic concentrations were significantly higher in comparison to all other wells. In particular chloride (54 mg/L) and sodium (22 mg/L) concentrations were high but nitrate (3.8 mg/L) concentrations were low. The low nitrates, similar $d^{18}O$ value to the Hinds River, close proximity to the River (50 m away) and water level fluctuations suggest significant Hinds River recharge. Knowing that the Hinds River has a lower overall ionic concentration to the groundwater sampled from this well, it is likely that the recharge source (dominantly from the Hinds River) has been enriched with nutrients derived from a source nearby. The only likely cause is a milking shed approximately 100 m up-gradient of the well. No other sources of contamination were identified.

8.10 Oxygen-18

Oxygen exists as two naturally occurring stable isotopes, oxygen-16 and oxygen-18. As rainfall is extracted from the atmosphere by condensation (due to a reduction in temperature), the $d^{18}O$ concentrations of the remaining vapour become more and more depleted (Stewart and Morgenstern, 2001). Consequently, $d^{18}O$ values become more negative at lower temperatures and higher altitudes. Rivers draining higher catchments transport this water with depleted $d^{18}O$ to the aquifers enabling the identification of high catchment river recharged groundwater from lowland rainfall recharged groundwater. $d^{18}O$ is expressed in units of parts per thousand ($^{0}/_{00}$) by the equation:

$$d\ (^{0}/_{00}) = \frac{R_{sample}}{R_{VSMOW} - 1} \times 1000$$

Where R is the ratio $^{18}O/^{16}O$ and VSMOW is Vienna Standard Mean Ocean Water (Clark and Fritz, 1997). Standard measurement errors for $d^{18}O$ are approximately 0.1 % (Stewart and Morgenstern, 2001).

8.10.1 Sampling programmes

$d^{18}O$ was sampled from 68 wells, 6 river localities, 3 irrigation race localities, 3 drains (10 locations) and 1 spring to help identify recharge sources. Prior to this study, $d^{18}O$ had been taken from seven wells (K37/0109, K37/0562, K37/0765, K37/1282, K37/1390, K37/1461 and K38/1020) between the Hinds and Rangitata Rivers (Stewart, 2006). In addition, $d^{18}O$ samples were taken from the Hinds River at Mayfield Bridge (site K37/2338) and the Rangitata River at State-Highway 1 (site K37/2339) between July 2003 and January 2005 (Figure 8.7).

8.10.2 Results and discussion

Figure 8.8 shows the spatial distribution of oxygen-18 over the field area. Samples were broken into three distinct groups (blue, green and red) based on $d^{18}O$ values.

Hinds and Rangitata Rivers

The Rangitata River and Irrigation Races had $d^{18}O$ values of -9.6 and -9.7 $^0/_{00}$ respectively. From previous sampling, the average value of the Rangitata River is -9.8 $^0/_{00}$ (Figure 8.7). In contrast the Hinds River at Mayfield Bridge was -8.63 $^0/_{00}$, more positive than the average of -8.9 $^0/_{00}$ (Figure 8.7). The more positive Hinds River water may be due to its lower altitude foothills derived flow, in contrast to the higher alpine catchment of the Rangitata River. Figure 8.7 suggests that $d^{18}O$ values become more negative soon after large flow events then less negative during periods of lower flow. At the time of sampling, the Hinds River (at Mayfield Bridge) flowed from a small spring fed creek. Had the south branch (from foothills derived water) been flowing downstream to Mayfield Bridge at the time of sampling, then the $d^{18}O$ value may have been more negative.

Blue Group

Samples from the blue group are highly negative (-9.82 – 9.30 $^0/_{00}$) and include Rangitata River, irrigation race water and wells generally close to the Rangitata River or main races. The highly negative values in wells K38/0517 and K38/1050 (both in aquifer one) suggest some Rangitata River recharge downstream of Storries Rd, confined within the RG2 gravel deposits (Figure 2.3). Much of the water in wells K37/0813 and K37/0493 (both in aquifer one) was likely sourced

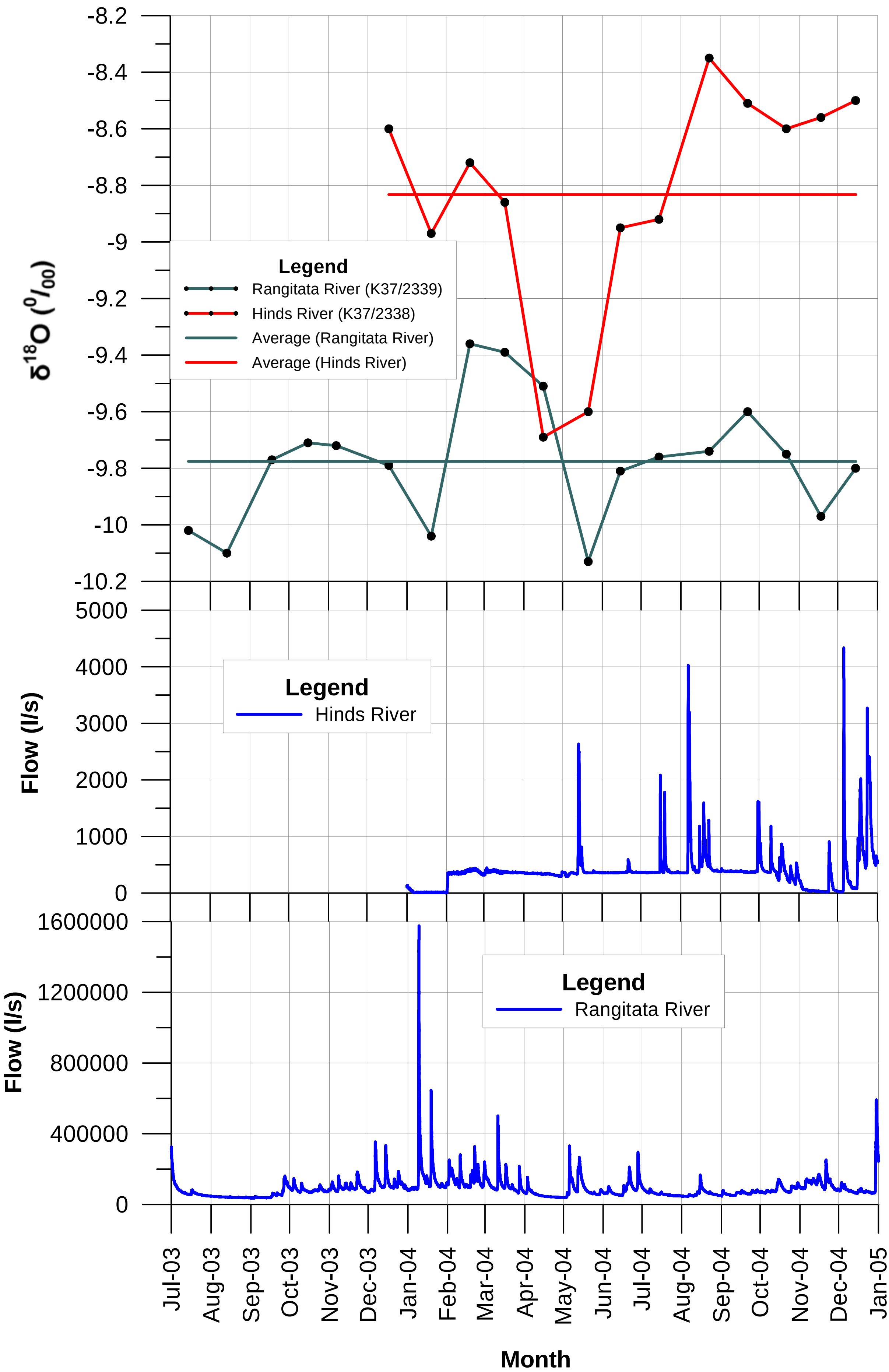

Figure 8.7 - Seasonal variations in oxygen-18 compared to river flow.

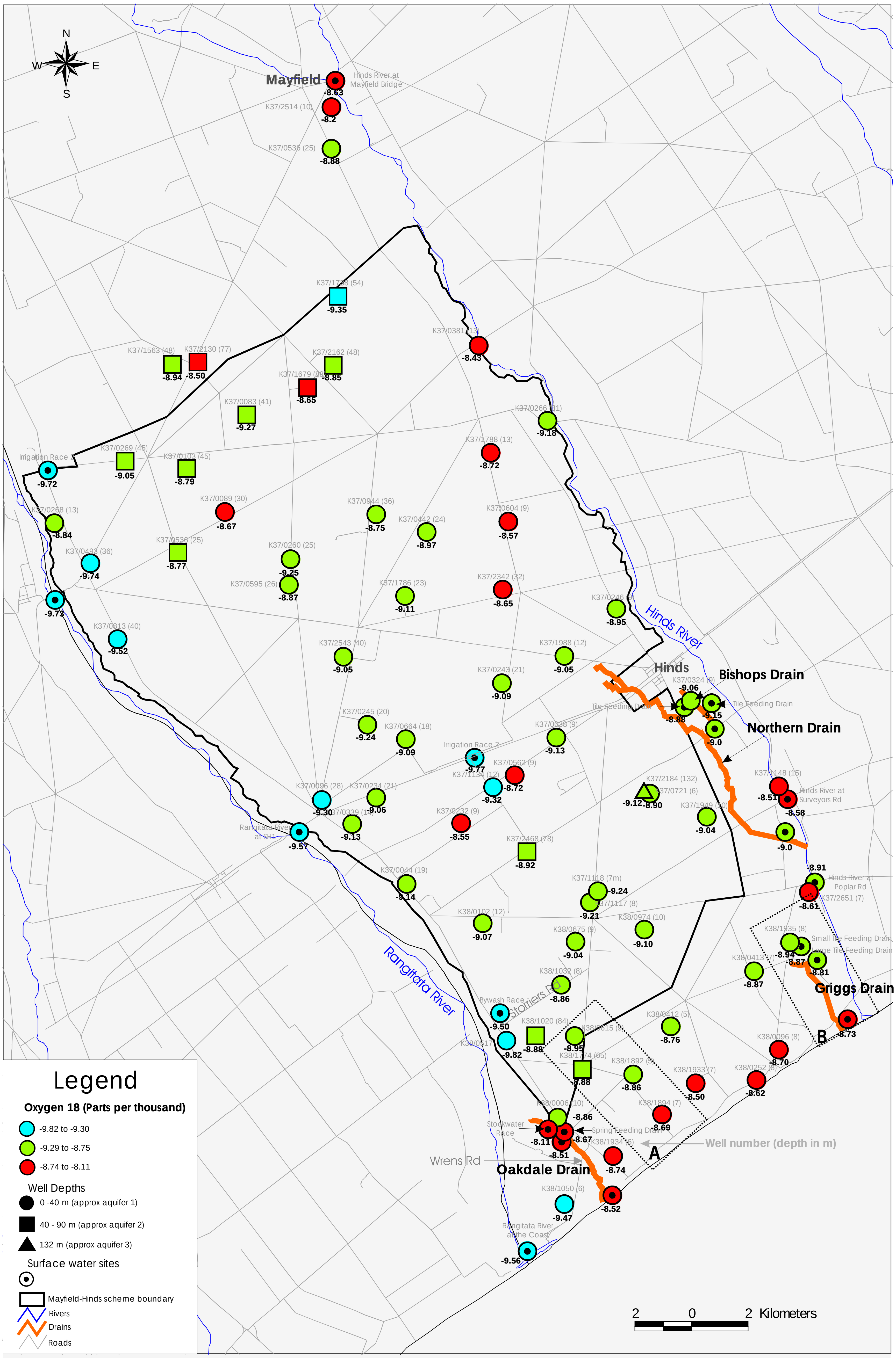

Figure 8.8 - Location and oxygen-18 results for all wells, rivers, races, drains, tile drains and springs sampled within the field area.

from the Rangitata River, the main race or a combination of the two. Wells K37/0269 (aquifer one or two?) and K37/1738 (aquifer two) are further from the Rangitata River and are likely recharged from Lateral 1 adjacent to Hackthorne Rd. The $d^{18}O$ value in all four wells close to main races may have been less negative had the sampling not occurred during the irrigation season. Well K37/1134 (12 m deep) was also highly negative. This well was far away from the Rangitata River and main irrigation races, thus this may have been caused by sampling coinciding with a local border-dyke irrigation event.

Green Group

Samples from the green group are dominantly Mayfield-Hinds Scheme recharged. $d^{18}O$ values are moderate - highly negative (-9.29 – 8.65 $^{0}/_{00}$) and include the majority of wells and drains from 3 - 4 km inland of the coast. For this area of the plains $d^{18}O$ values between -7.8 and -8.6 $^{0}/_{00}$ would be expected (Stewart et al, 2002). The highly negative $d^{18}O$ is likely caused by highly negative Rangitata River derived recharge from the Mayfield-Hinds Scheme. This suggests that irrigation recharge water is mixing with and diluting much of the rainfall recharge. These highly negative $d^{18}O$ values were also observed in three second aquifer wells and one third aquifer well, suggesting that scheme water is directly recharging the deeper aquifers. In Chapter 5.5 it was shown that aquifers one and two had almost identical water level fluctuations in response to scheme recharge. Though the almost simultaneous water levels rise are likely due to a pressure effect, the $d^{18}O$ values suggest that over time (period unknown) this irrigation water will pass from the first to the second and possibly the third aquifer. The absence of a confining layer between aquifers one and two (Chapter 3.11) may aid in the movement of irrigation water down into aquifer two. In contrast, the highly negative $d^{18}O$ values may suggest the deeper aquifers are recharged by more negative foothills rainfall. If this is occurring then the water level rise in response to the Mayfield-Hinds Scheme in all deeper aquifers, is dominantly caused by a pressure effect. Of note is the green group value for well K37/1563 up-gradient of the scheme. The water level in this well rose 3 m in response to scheme recharge. The highly negative $d^{18}O$ value suggests that the rise could have been caused by some direct scheme recharge and not just a pressure effect.

Drain water, spring and tile drain water had similar $d^{18}O$ values to adjacent groundwater samples. A large scheme recharge effect is shown in Bishops and the Northern Drain (Chapter

6.3.3) and a small scheme recharge effect is shown in Oakdale Drain (Chapter 6.3.6). This is reflected by more negative d^{18}O values in the Northern Drain in contrast to the red group values in Oadkadale Drain. The less negative d^{18}O values in Oakdale Drain were not only caused by the increased dominance of rainfall, but also by the relatively positive value of the Stockwater Race (sourced from the Rangitata River) flowing into the drain. The relatively positive d^{18}O value of the stockwater is likely caused by open water evaporation which causes the water to become less negative. At the time of sampling this race accounted for approximately 25% of the flow sampled in the drain upstream of Wrens Rd. In contrast to the three previously mentioned drains, Griggs Drain showed no scheme recharge effect despite the highly negative d^{18}O values. This may have been caused by a relatively consistent gradual seepage of scheme water down-gradient with changes in flow being more influenced by local effects such as rainfall. A notable trend is the progressive change to more positive d^{18}O water from the start of the drain to the coast (Figure 8.8 Block B). This suggests that the drain gains in flow downstream from dominantly rainfall recharged groundwater.

Red Group

Samples from the red group include a mixture of dominantly Hinds River, scheme and rainfall recharged water. Most wells within this group occur close to the Hinds River or coastward of the Mayfield-Hinds Scheme. Oxygen-18 values are moderately negative (-8.74 to -8.11$^{0}/_{00}$) but considerably more negative than would be expected for most of these wells and drain sites at each location. At the time of sampling the Hinds River at Mayfield Bridge was -8.63 $^{0}/_{00}$. In addition, the water level in wells K37/2514 and K37/0381 are known to be affected by the Hinds River near this location (Chapter 4.4.2). Thus Hinds River recharge would explain the more positive d^{18}O in both of these wells. Upstream of Hinds Township, less negative d^{18}O values occur in three shallow wells, all within 4 km of the river (Figure 8.8). In this area, water levels in aquifer one rose significantly (2 – 5 m) from scheme recharge (during this study) with no effects observed from the Hinds River and minimal effected from the heavy winter (2006) rainfall. Thus two reasons for the less negative values include incomplete mixing of scheme and rainfall recharge water or that Hinds River water recharged this area some time prior to sampling. Downstream of Hinds Township at Surveyors Rd, well K37/1148 (aquifer one) had a similar red group value to the Hinds River, suggesting river recharge, also evident from water level fluctuations in this well. Within 3 km of the coast, groundwater in aquifer one rapidly becomes less negative suggesting dominantly rainfall recharge. This is evident in the Stiff plot patterns and seasonal groundwater level fluctuations in this area.

Overall Effect from the Mayfield-Hinds Irrigation Scheme

Based on lysimeter data, Stewart et al (2002) estimated an average $d^{18}O$ value of -7.6 to -8.4 $^{0}/_{00}$ for the lowland to mid plains (0 – 25 km inland) and -8.4 to -9.2 $^{0}/_{00}$ for to mid to inland plains (25 – 50 km inland) rainfall recharged groundwater. In contrast, the least negative $d^{18}O$ values (Red Group) in the Hinds Plains occurring within the old Hinds Swamp (near the coast) ranged between -8.5 and -8.74 $^{0}/_{00.}$ $d^{18}O$ values between -7.6 and -8.0 $^{0}/_{00}$ would be expected in this area based on $d^{18}O$ data from other coastal areas. Thus the highly negative $d^{18}O$ values suggest some Mayfield-Hinds Scheme recharge derived from highly negative Rangitata River water, despite the fact that little or no summer groundwater level rise occurred in this area. Water levels in wells K38/0517 and K38/1050 showed very little (if any) responses to changes in flow in the Rangitata River, however both wells exhibit a distinct $d^{18}O$ and Rangitata River chemistry. In addition, the high water table and significant number of drains within this area vastly restrict the water level rise and seasonal fluctuations thus any effect whether immediate or delayed is very difficult to observe. Thus there could be a consistent gradual seepage of Rangitata River derived irrigation water through this coastal section of aquifer one which is not obviously observable from water level fluctuations.

Boxes A and B show how $d^{18}O$ becomes progressively less negative between 0 and 5 km inland from the coast, showing a progressive increase in the dominance of rainfall over scheme recharge. This is also shown by the reduced summer water level rise in wells K38/0384, K38/0517, K38/1892 and K38/1894, and the increased ionic concentrations in the Stiff plot patterns (Figure 8.2).

8.11 Summary and Conclusions

Three types of groundwater and two types of river water occurred within the Hinds Rangitata Plain. Groundwater was a calcium bicarbonate, calcium nitrate or a non dominant type, Rangitata River derived water was a calcium bicarbonate type and Hinds River water was a non dominant type.

Groundwater dominantly derived from river recharged sources occurred adjacent to the Hinds River, adjacent to the Rangitata River (near Arundel Bridge and downstream of Storriers Rd) and adjacent to some of the main irrigation races. Within the Zone 1, groundwater in aquifer one shows a progressive reduction in the percentage of bicarbonate and progressive increase in the percentage of sulphate down Plain. In contrast, the percentage of chloride remains relatively similar, with no spatial trend in cations. The thicker unsaturated zone and greater ability of drainage water to gain nutrients and minerals before entering the groundwater system is a likely reason for the higher overall ionic concentration, and higher calcium and bicarbonate concentrations further inland.

Between the Mayfield-Hinds Scheme and the coast groundwater is dominantly rainfall recharged. In this area, both the total ionic and chloride concentrations are highest. This is caused by coastal precipitation containing higher ionic concentrations and the reduction (or absence) of scheme recharge meaning that there is little or no dilution (from Rangitata River derived irrigation water) of the nutrient enriched rainfall recharge water. Within the Mayfield-Hinds Scheme and coastward of State-Highway 1, all second and third aquifer wells had a distinctly different chemistry with water containing high concentrations of calcium and bicarbonate and low concentrations of nitrate. Three wells had a chemistry which did no fit with the main Stiff plot groups identified above. The differences in chemistry may reflect site specific influences.

The spatial pattern of $d^{18}O$ suggests the same general pattern of recharge as the Stiff plots and Piper diagrams. $d^{18}O$ is most negative adjacent to the Rangitata River and main races, and relatively positive adjacent to the Hinds River. These values are similar to the rivers themselves and suggest losses some recharge to groundwater. $d^{18}O$ values within the Mayfield-Hinds Scheme are highly negative compared with other areas of Plains at similar distances inland from the coast. This is likely caused by scheme recharge sourced from highly negative Rangitata River water. Down-gradient of the scheme, $d^{18}O$ becomes less negative in response to the increased dominance of rainfall recharge. However, the values are more negative than expected at this location, suggesting that scheme water is flowing all the way to the coast. Highly negative values within aquifers two, three and up-gradient of the scheme (in aquifer one or two?) suggest direct recharge from the scheme. This would mean that groundwater level rises in response to the scheme recharge are not only caused by a pressure effect.

Chapter Nine

Summary and Recommendations

9.1 Introduction

Prior to this study, no water balance had been carried for the Hinds Rangitata Plain. In addition, little or no research had been carried out into the water level fluctuations in aquifers two, three and aquifer one near the coast, the flow regime of the Hinds Drainage Network, the sources of flow in the Hinds River, and the spatial variability of the groundwater chemistry.

To gain a better understanding of the surface and groundwater resources of the Hinds Rangitata Plain, the primary objectives of this study were to:

- Delineate all aquifers present in the study area and characterize their properties.
- Determine the long-term and short-term affects of rainfall, Mayfield-Hinds Irrigation Scheme and river recharge, on groundwater levels, both spatially and with depth in all aquifers.
- Understand the affects of groundwater levels and rainfall on spring and drain flows.
- Understand the flow regime and sources of flow within the Hinds River.
- Provide a water balance showing the relative contributions of each recharge and discharge component of the groundwater system.
- Identify sources of recharge and groundwater flow paths based on water chemistry and oxygen-18 ($d^{18}O$).

9.2 Thesis Summary

9.2.1 Geology and geomorphology

The majority of the Hinds Rangitata Plain as formed during glacial periods within the Late Quaternary, approximately 400,000 ago to present. Gravel deposits are dominantly glacial outwash, sourced from the Rangitata River and occur to a depth of 600 m. Ashburton River deposits are restricted to a narrow, 6 – 10 km sector of Plain between the Rangitata River and

Rakaia River fans. The smaller unglaciated Hinds River, occupied the depression between the two larger Rangitata and Ashburton River fans. During postglacial times the Hinds River originally flowed into a swamp half way between Boundary and Surveyors Rd. Bacterial processes within this swampy area are believed to have resulted in the deposition of generally impermeable limonite (ironstone) formations. These are thought to be partly responsible for higher water table areas, the occurrence of springs and perched water table at some locations.

If finely braided channels were deposited by the Rangitata River and not eroded at the time of deposition or post deposition, then the majority of the Hinds Rangitata Plain aquifers may occur as a large number of wide, highly interconnected channels. However from outcrop observations aquifer one (and likely aquifers two and three) occurs as a series of permeable, often iron stained, poorly connected and laterally discontinuous lenses, within and often separated by less permeable sandy or tight claybound gravels. These lenses are likely remnants of larger channels eroded by scour and fill processes, during and post-deposition.

9.2.2 Hydrogeology

Three aquifers occur within the Hinds Rangitata Plain. Aquifer one extends from near surface to approximately 40 – 50 m, though a possible aquitard from 20 – 40 m could be present coastward of State Highway 1. Aquifer two occurs from approximately 40 – 90 m, with a separate second aquifer in Hydrogeological Section 4A (refer to Figure 3.2 in the back pocket), inland of Winslow Rd, close to the Hinds River. Aquifer three occurs from approximately 90 – 150 m. A possible aquitard of less permeable claybound gravel occurs between 90 and 120 m depth. The likely cause of dry first and second aquifer wells is that they are not adequately penetrating the entire width of the aquifer.

In all three aquifers depth to groundwater increases with increasing distance inland from the coast, and in aquifers one and two one water level fluctuations are known to increase with increasing distance inland from the coast. Aquifer two water levels are generally 1 – 5 m lower than aquifer one with the exception at the coast where water levels are higher in aquifer two, and in Hydrogeological Section 4A, where the separate second aquifer has a significantly deeper water level.

Specific capacity and transmissivity is variable and often difficult to interpret when comparing galleries with wells. Groundwater flow in aquifers one and two is from the foothills to the coast. Aquifer one gains and losses groundwater along different sections of the Hinds and Rangitata Rivers, insufficient data was available to determine river losses and gains in aquifer two.

9.2.3 Groundwater level fluctuations

The Hinds Rangitata Plain was broken (spatially) into seven distinct zones based on differences in the dominant source (s) of groundwater recharge within each zone. A map showing the zone boundaries is provided in Figure 4.1 in the back pocket. The boundaries for each zone were determined by comparing the short-term seasonal water level fluctuations observed over the course of this study and the long-term water level records, with rainfall, river flows and Mayfield-Hinds scheme recharge.

Zone 1

In Zone 1, the Mayfield-Hinds scheme has been the dominant source of groundwater recharge since 1982. Since this time, groundwater levels in aquifers one and two have on average, been highest from March to April and lowest from September to October. In aquifers one and two the water levels rise in response to rainfall and scheme recharge is highest near Carew (10 – 12 m) and reduces with increasing distance up-gradient, north towards the Hinds River, coastward to approximately Emersons Rd, and down-gradient of Hinds Township to approximately half way between Boundary and Surveyors Rd. In contrast, water level fluctuations in aquifer three and the separate second aquifer (located in Hydrogeological Section 4A) suggest a delayed scheme recharge effect, between January and February.

Winter rainfall has a significant influence on the long-term water level trends in Zone 1. In addition, there is also an important relationship between rainfall and scheme recharge, and the resultant influences on spring flows and drainage in the higher water table areas within Zone 1. Early on in the irrigation season, water levels also rise from race losses to groundwater.

Zone 2

Rainfall is the dominant source of recharge with less but still significant scheme recharge (pressure induced effects) occurring at specific locations. During the course of this study, the water level in wells K37/1563 (48 m deep) and K37/2551 (67 m deep), rose 3 – 4 m in response to scheme recharge (both 1.6 km up-gradient of the scheme). This groundwater level rise was likely caused by a pressure effect propagating up-gradient of the scheme. In contrast, historic water level data from well K37/0271 (30 m deep), 1.7 km up-gradient of the scheme shows a strong correlation to rainfall with no evidence of scheme recharge. It is not known why a scheme induced recharge only occurs in some wells.

Zone 3

In Zone 3, rainfall is the dominant source of recharge. The exception occurs within drain sourced border-dyke areas where groundwater levels rise each summer. Groundwater levels in aquifer one are on average, highest from May to June and lowest in December. Seasonal groundwater level fluctuations are small (approximately 75 cm) because of the high water table (less than 2 m below ground level) and the large number of springs and drains, which discharge a significant proportion of the recharge. Water levels in aquifer two may rise each summer in response to scheme recharge however this is not certain due to the local border-dyke affects at the site where this was observed. Tidal affects occur in both aquifers one and two, and occur in aquifer two to at least 2.0 km inland from the coast. Tidal affects on water levels decrease in magnitude and lag in time with increasing distance inland from the coast.

Zone 4

The Hinds River is the dominant source or recharge to aquifer one with a smaller but still significant contribution from rainfall. During low flow in the Hinds River, the water table slopes in towards the river. During high flows the water table slopes away from the river suggesting a change in groundwater flow direction during times of alternating high and low river flows.

Zone 5

Aquifers one and two are dominantly rainfall recharged, with the boundary between dominantly rainfall and dominantly Hinds River recharged groundwater, extending 1.5 km distance out from the Hinds River. Towards the centre of the Rangitata fan, away from the Hinds River, groundwater level fluctuations are likely to be larger than in any other area on the Hinds Rangitata Plain. Rainfall events have the potential to cause the greatest rise in groundwater levels any where on the Hinds Rangitata Plain.

Zone 6

Water level fluctuations show subtle recharge effects from the Rangitata River and no response to Mayfield-Hinds scheme recharge in contrast to nearby wells within Zone 1. Significant water levels rise in response to rainfall and the general coinciding of rainfall with peak river flow and water levels suggest that rainfall and river losses are the dominant recharge sources

Zone 7

Losses to groundwater from the Hinds River account for the majority of groundwater recharge to aquifer one from Mayfield Township to 14 km downstream. Recharge from the Hinds extends 1.5 km away from the river. With increasing distance away from the river, the water level rise during high flows is reduced in magnitude and delayed in time with.

Following a large flow event, the water level rose for at least 3.5 km downstream of where the Hinds River stopped flowing. This suggests a wave of water propagating downstream in front of the surface flow. Where this wave of water intercepted the land surface springs within the bed of the river started flowing.

9.2.4 Surface hydrology and springs

Springs

The majority of springs within field area are depression springs, located between Coldstream Rd and the old Hinds Swamp. Those that occur within the Zone 1 (Figure 4.1 in the back pocket) are dominantly affected by border-dyke irrigation. In contrast, springs within Zone 3 are dominantly affected by rainfall. Most springs emitting from the northern bank of the Rangitata River terrace are also highly affected by the Mayfield-Hinds scheme, as are the depression springs within the Hinds River from Dicksons Rd to State-Highway 1.

Drains

The flows in drains that occur within or partly within groundwater recharge Zone 1, show a general summer rise in response to rising groundwater levels. The flows in drains that occur within Zone 3 are generally highest in mid winter and are dominantly affected by rainfall. In all cases drain flows are significantly increased by large local rainfall events.

Hinds River

During periods of low rainfall both branches of the Hinds River are generally dry near at Mayfield Bridge. As a consequence, the flow at Mayfield-Bridge is likely to be sourced from a spring fed flow of water from Silver Stream Creek. This flow dries up within 1 – 2 km downstream of the Mayfield Bridge. From Mayfield, downstream to approximately Dicksons Rd, the Hinds River is dry with the exception intermittent bywash releases and springs within the bed of the river that may flow in response to both Hinds River recharge and rainfall. Between Dicksons Rd and State-Highway 1, a summer groundwater level rise in response to Mayfield-Hinds scheme will cause springs within this section of the river bed to either start flowing or increase in flow. Over time this flow may join with the flow of water downstream of Boundary Rd. This section is also highly affected by bywash released from Lateral 3. Halfway between Boundary and Surveyors Rd there is a consistent flow of water downstream to the coast. Between Surveyors and Poplar Rd the Hinds River gains a considerable flow of water from drains. During wet periods the Hinds River will flow for its entire length as a result of foothills rainfall runoff. During periods of high flow a considerable amount of the surface flow is lost to groundwater, especially between Mayfield Bridge and Boundary Rd.

Rangitata River

Unlike other major rivers such as the Rakaia and Ashburton, the Rangitata River shows no losses in flow. In addition, the river may gain in flow downstream of State-Highway 1 when adjacent groundwater levels are high. Piezometric contours also suggest little if any losses in flow, though this is likely dependent on the groundwater level of the adjacent water table.

Distribution Races

Gaugings of a Mayfield-Hinds scheme distribution race suggest flow losses in the order of 7 l/s per kilometer. Due to an 8 percent margin of gauging error and the fact that only one race was accurately gauged, it is impossible to say whether this loss of flow is typical. However it is likely that losses from distribution races are an important source of groundwater recharge.

9.2.5 Regional water balance

A regional water balance of the Hinds Rangitata Plain was carried out for a one period, between September 2005 and August 2006. During this period, total recharge was 375 $m^3 \times 10^6$, total discharge was 227 $m^3 \times 10^6$, with an outflow of 148 $m^3 \times 10^6$. Data collected during the course of this study showed that rainfall recharge was dominant, accounting for 67 % of the total recharge. The Mayfield-Hinds scheme accounted for 30 % of the total recharge, with a relatively small contribution each from the Rangitata Diversion Race and Hinds River. In terms of discharge, the combined discharge from the drains and Rangitata River terrace springs, accounted for 62 % of the total discharge, with the remaining discharge from coming from groundwater abstraction. There are no overall losses to groundwater from either the Rangitata River or from stockwater races.

As a consequence of low summer rainfall, the Mayfield-Hinds scheme accounted for approximately 64 % of the total recharge from the Hinds Rangitata Plain, over the 2005/06 irrigation season. Despite a significant recharge contribution from the scheme, drain discharges were shown to be dominantly effected by rainfall. Groundwater outflow to the ocean is shown to be highly variable depending on the ratio of recharge to discharge. It is likely that during periods of high groundwater abstraction, and or high drain flows, groundwater discharge could be greater than groundwater recharge.

9.2.6 Hydrochemical facies and recharge sources

Three types of groundwater and two types of river water occurred within the Hinds Rangitata Plain. Groundwater was a calcium bicarbonate, calcium nitrate or a non dominant type, Rangitata River derived water was a calcium bicarbonate type and Hinds River water was a non dominant type.

Groundwater dominantly derived from river recharged sources occurred adjacent to the Hinds River, adjacent to the Rangitata River (near Arundel Bridge and downstream of Storriers Rd) and adjacent to some of the main irrigation races. Within the Zone 1, groundwater in aquifer one shows a progressive reduction in the percentage of bicarbonate and progressive increase in the percentage of sulphate down Plain. The thicker unsaturated zone and greater ability of drainage water to gain nutrients and minerals before entering the groundwater system is a likely reason for the higher overall ionic concentration, and higher calcium and bicarbonate concentrations further inland.

Between the Mayfield-Hinds scheme and the coast groundwater is dominantly rainfall recharged. In this area, both the total ionic and chloride concentrations are highest. This is caused by coastal precipitation containing higher ionic concentrations. Within the Mayfield-Hinds scheme and coastward of State-Highway 1, all second and third aquifer wells had a distinctly different chemistry with water containing high concentrations of calcium and bicarbonate and low concentrations of nitrate.

The spatial pattern of $d^{18}O$ suggests the same general pattern of recharge as the Stiff plots and Piper diagrams. $d^{18}O$ is most negative adjacent to the Rangitata River and main races, and relatively positive adjacent to the Hinds River. $d^{18}O$ values within Zone 1 are highly negative compared with other areas of Plains at similar distances inland from the coast. This is likely caused by scheme recharge sourced from highly negative Rangitata River water. In Zone 3, $d^{18}O$ becomes less negative in response to the increased dominance of rainfall recharge. However, the values are more negative than expected at this location, suggesting that scheme water is flowing all the way to the coast. Highly negative values within aquifers two, three and up-gradient of the scheme (in aquifer one or two?) suggest direct recharge from the scheme. This would mean that groundwater level rises in response to the scheme recharge are not only caused by a pressure effect.

9.3 Recommendations for Future Research

9.3.1 Defining the nature and occurrence of the aquifer two in Hydrogeological Section 4A

Groundwater level fluctuations and an overall deep water level (compared with aquifer one) show that the second aquifer in Hydrogeological Section 4A, is distinctly different to the second aquifer over the remaining Hinds Rangitata Plain. This is likely related to geology. In addition many wells in this aquifer have gone dry over the past five years. Thus it is recommended that additional research be carried out to define the hydrogeology and geologic differences between this second aquifer and the second aquifer over the remaining Hinds Rangitata Plain.

9.3.2 Additional second and third aquifer monitoring wells

It is recommended that additional second and third aquifer wells be used for water level monitoring. The area of highest priority is up-gradient of the Mayfield-Hinds scheme where a significantly large number of deep (80 – 200 m) irrigation wells are proposed. Currently there are no monitoring wells in this area.

9.3.3 Hinds River water balance

Additional gaugings of the Hinds River, inflow to the river and data on the outflow (if abstractors are taking water) is needed to confirm or reject the findings of the single gauging run carried out during this study. Gauging runs should be carried out when the river is flowing for its entire length (dominantly rainfall feed flow) and when the river is relative dry (dominantly groundwater feed flow). This data will provide information on the losing and gaining sections of the river and the relative contribution from groundwater sourced springs and drains.

9.3.4 Detailed piezometric survey adjacent to the rivers

A detailed piezometric survey of wells in both aquifers one and two should be carried out both sides of the Hinds and Rangitata Rivers. It would also be useful to carry out a gauging run of each river at the time of the piezometric survey. The combined data would provide more accurate information on river losses and gains.

9.3.5 Rangitata River losses and gains to groundwater

It was noted that losses and gains from the Rangitata River likely change over time as a consequence of water level fluctuations in the adjacent aquifers. In order to prove that this occurs, the heights above sea level for the Rangitata River and adjacent wells should be surveyed. This would show whether the adjacent water levels are higher or lower than the surface of the Rangitata River.

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